Space, Spatiality, and Epistemology in Hooke, Boyle, Newton, and Milton

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May 2014

I declare that this thesis has not been and will not be submitted in whole or in part to this or any other University for the award of any other degree.

I declare that this submission is my own work. Where reference is made to the works of others, the extent to which that work has been used is indicated and duly acknowledged in the text.

Signed:

Acknowledgements

I am grateful to the AHRC for a full fees and maintenance grant, and to the University of Sussex School of English for an initial bursary.

My thanks and warm regards go out to the administrative staff at the University of Sussex, and to the staff and librarians at The British Library, Cambridge University Library, Cambridge English Faculty Library, Heythrop College Library, The Maughan Library, The Royal Society, Senate House Library, University of Sussex Library, The Warburg Institute Library, and The Wellcome Library.

I could not have asked for better doctoral supervision and my heartfelt thanks go to Brian Cummings and Andrew Hadfield who have both challenged and supported me throughout this venture with encouragement, inspiration, and deep critical insight.

A number of readers and auditors have commented most helpfully on various parts of my thesis. My sincere thanks to Liza Blake, Freya Sierhuis, Rob Illiffe, Chloe Porter, Paul Quinn, Tom Healy, Margaret Healy, and Julia Banister, and to commenters at the 'Milton:Newton, Two Cultures?' conference at the University of Sussex (2009), the Inaugural Conference of the Centre for Material Texts at the University of Cambridge (2010), and the 'Passions and Subjectivity in Early Modern Culture' workshop and conference at Ludwig Maximilians Universität (2010 and 2011).

Special thanks to Gavin Alexander for encouraging me to undertake this doctoral project in the first place, to Liza Blake for her meticulous reading of much of the thesis and her generous and unfailing intellectual and culinary support, and to my sister, Sarah Tollar, for always inspiring me. Finally, for teaching me to read and for always supporting me even when I refused to stop, I thank my parents, Peter and Madi Fletcher, without whom this work would not have been possible and to whom it is gratefully dedicated.

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SUMMARY

In this thesis I trace the relations between thinking about space and the spatiality of thought as it relates to epistemology in the eponymous authors. I argue that the verbal, visual, and mental tools used to negotiate the ideas and objects under consideration are not merely representative or rhetorical, but are part of the process of knowledge-making itself. I contend that the spatialities of language, visual presentation, and mental image facilitate new ways of seeing and the exploring of previously invisible relationships. I show how the dynamic spatiality of the imagination is used for testing hypothesis, considering multiple points of view, accommodating uncertainties, and thinking about expansive ideas that push at (or exist beyond) the boundaries of the known or possible. In this way I offer new readings of key texts that foreground the inherent relativity of human experience, which I contend is at the heart of a scientific uncertainty found even in the new science that strove for objectivity. In four case studies I explore the relationship between external and internal space in the thinking and perceiving subject, building on Steven Connor's assertion that 'thinking about things is unavoidably a kind of thinking about the kind of thing that thinking is' ('Thinking Things', 2010). In addition to this unidirectional relation between thinking and things, I demonstrate a complex dialogue between interior (thought) and exterior (thing) that occurs in the ways processes of thought and perception are externalized on the page and with instruments of viewing; in the way objects are brought into the mind; and in the way the mind creates infinities within by tracing expansive external spatialities.

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List of Abbreviations

BP	London, The Royal Society, Boyle Papers
Certain Physiological Essays	Boyle, *Certain Physiological Essays, Written at Distant Times, and on Several Occasions* (1661)
Christian Virtuoso, I	Boyle, *The Christian Virtuoso: Shewing, That by Being Addicted to Experimental Philosophy, a Man is Rather Assisted, than Indisposed, to be a Good Christian* (1690–1691)
Complete Shorter Poems	John Milton, *Complete Shorter Poems*, ed. by John Carey, 2nd edn (Harlow: Longman, 1997)
Correspondence	*The Correspondence of Isaac Newton*, ed. by H. W. Turnball, 7 vols (Cambridge: Cambridge University Press, 1959–1977)
CPW	*Complete Prose Works of John Milton*, ed. by Don M. Wolfe, 8 vols (New Haven: Yale University Press, 1953–82)
Defence and *Examen*	Boyle, *A Defence of the Doctrine Touching the Spring and Weight of the Air* and *An Examen of Mr T. Hobbes his Dialogus Physicus De Natura Aeris* (1662)
ELH	*English Literary History*
General History of Air	*The General History of the Air, Designed and Begun by the Honourable Robert Boyle Esq.* (1692)
Medicina Hydrostatica	Boyle, *Medicina Hydrostatica: or, Hydrostaticks Applied to the Materia Medica* (1690)
Posthumous Works	*The Posthumous Works of Robert Hooke*, ed. by Richard Waller (London: Sam Smith and Ben J. Walford, 1705)
PR	*Paradise Regained* (in *Complete Shorter Poems*)
Principia	Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. by I. Bernard Cohen and Anne Whitman (Berkeley: University of California Press, 1999)
Principia (1687)	Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (London: Joseph Streater, 1687)

PW	Isaac Newton, *Philosophical Writings*, ed. by Andrew Janiak (Cambridge: Cambridge University Press, 2004)
Seraphic Love	Boyle, *Some Motives and Incentives To the Love of God. Pathetically Discours'd of, in a Letter to a Friend* (1659)
Spring, 1st Continuation	Boyle, *A Continuation of New Experiments Physico-Mechanical, Touching the Spring and Weight of the Air, and their Effects. The First Part.* (1669)
Spring, 2nd Continuation	Boyle, *A Continuation of New Experiments Physico-Mechanical, Touching the Spring and Weight of the Air, and their Effect. The Second Part* (1682)
Spring of the Air	Boyle, *New Experiments Physico-Mechanicall, Touching the Spring of the Air and its Effects* (1660)
Things above Reason	Boyle, *A Discourse of Things above Reason. Inquiring Whether a Philosopher Should Admit There Are Any Such* (1681)
Usefulness, I	Boyle, *Some Considerations touching the Usefulnesse of Experimentall Naturall Philosophy. The First Part* (1663)
Works	*The Works of Robert Boyle*, ed. by Michael Hunter and Edward B. Davis, 14 vols (London: Pickering & Chatto, 1999–2000)

Prologue

Shortly before his death, Newton reportedly described himself:

> Like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.[1]

This quotation is widely held to contain reference to Milton's attack in *Paradise Regained* on the incessant reader who fails to bring to his reading 'a spirit and judgment equal or superior' as being:

> Deep-versed in books and shallow in himself,
> Crude or intoxicate, collecting toys,
> And trifles for choice matters, worth a sponge;
> As children gathering pebbles on the shore.[2]

The anecdote is a favourite of biographers keen to show a link between Newton and his contemporary literary culture, or to demonstrate to the non-specialist reader some more readily accessible beauty in a life of arcs and angles. However, the quotation is not just a pretty image or a pleasing intertextuality. With an ironic inversion of the supposed humility of his statement, Newton rehabilitates Milton's metaphor by recontextualizing its space. The imagery of Milton's reader is closed in — any depth to the reader's learning is constrained by the image of the book as container ('*in* books' (my emphasis)) and undermined by his shallowness in himself. It is petty and trivial; the pebbles — deemed of little worth — are the end purpose of the reader's book learning and the shore is just a location. But Newton's image is expansive, limitless even. He zooms out on the scene and turns the shore into a metaphor for the edge of knowledge by placing it at the boundary of the ocean of undiscovered truth. As such, the pebbles become not an end purpose, but a starting point for a much wider exploratory venture. They take on greater value because of this, even though they are smaller pieces of the

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[1] David Brewster, *Memoirs of the Life, Writings, and Discoveries of Sir Isaac Newton*, 2 vols (Edinburgh: Thomas Constable, 1855), II, 407.

[2] John Milton, *Complete Shorter Poems*, ed. by John Carey, 2nd edn (Harlow: Longman, 1997), 'Paradise Regained', IV. 322–30.

larger image.

The search for these pebbles also becomes elevated. There is a sense of discovery and development to Newton's play; it is not mere collection for its own sake. He finds new things and, as suggested by the comparative adjectives *smoother* and *prettier*, distinguishes them. This use of judgment to categorize and bestow value on his findings echoes empirical methods of natural history, methods which contrast with myopic book learning, redolent of scholasticism, and which are more evocative of the fit reader of *Areopagitica*, whom Milton argues is 'sufficient both to judge aright, and to examine each matter'.[3] Newton's gathering takes him into the realm of new knowledge, and the connection he makes between his work of 'finding' on the shore and the 'undiscovered' ocean of truth echoes Milton's Isis-like search for the scattered limbs of truth, 'searching what we know not, by what we know' (*CPW*, II, 551), rather than just assimilating established ideas. The shifting boundary between shore and sea — Newton expands Milton's 'shore' to 'sea-shore' and the shells and pebbles he examines are items cast up by the ocean of truth itself — suggests both the proximity and interrelation of the known and the unknown. Newton's image acknowledges the limits of the current state of human learning, but is latent with potential for the future acts of mankind: the ocean of truth is not unknowable, it is merely as yet undiscovered.

Newton's image captures some of the key concerns of this thesis. It imbricates a spatial metaphor for knowledge (the ocean and sea-shore) with the scientific object itself (the pebbles and shells examined, *make up* the sea-shore), at the boundary between the known and the unknown (both the spatial boundary of the sea-shore image and the moment of discovery in the act of finding and examining). In so doing it relates the seemingly narrow focus of discrete and atomic attention to a much more expansive project of discovery and knowledge making. It also does so in a way that foregrounds both the potential capability and the subjective experience of the practitioner himself, which obviates the shallowness of self possessed by Milton's reader by engaging the capacity of man both with the external world and with the expanse of the unknown that is waiting to be discovered. Newton's similetic description of himself also reveals the value of linguistic devices and imagery to think through scientific and epistemological

[3] *Complete Prose Works of John Milton*, ed. by Don M. Wolfe, 8 vols (New Haven: Yale University Press, 1953–82), II, 511. Further references to this edition are denoted *CPW* and given by volume and page number parenthetically in the text.

concepts, and the potential effect on the understanding of an object when one approaches it with a new spatial understanding.

In this thesis I examine these concerns by means of four case studies on different writers, each exploring different kinds of space. I investigate the relationships between their ideas about and investigations into physical, objective space; their ideas about epistemology, particularly the accommodation of the unknown or uncertain; and the mental, verbal, and visual tools (which have their own spatiality) that they use to understand and convey that work. In this way I combine a study of the philosophical concerns of thinking about space and spatial thinking with an interest in a more practical kind of spatiality, that of the verbal and visual methods of the page. I am interested in the spatial imagination and how this relates to our external experience of space. As Kate Flint suggests in her study of the Victorian visual imagination, 'Seeing in the mind's eye was linked to scrutinising the world around one, but it was not an identical process.' I follow Flint's lead in paying close attention to 'the slipperiness of the borderline between the visible and the invisible, and the questions which it throws up about subjectivity, perception and point of view'.[4]

The setting for my thesis is mid- to late seventeenth century England: the early days of the Royal Society. While it is important to avoid the anachronism and the reductive, positivist implications of the idea of a 'Scientific Revolution', it is significant that during the early modern period a range of developments in technology and method were made, which, in the new ways of looking this afforded, entailed the opening up of new spaces and the re-imagining of old ones. Outer space became more vast and subject to new theories about its structure; minute objects were viewed at magnification revealing a new world only appreciable with a change of scale; the concept of vacuum gained greater acceptability; and in some circles corpuscularian theories of matter took hold. Concurrent with the emergence of these new focuses for natural philosophical enquiry, developments in epistemology also occurred. As Barbara J. Shapiro's seminal work shows, 'The new philosophy was fashioned from a reconsideration of what constituted science or knowledge, a re-evaluation of opinion and probability, and the

[4] Kate Flint, *The Victorians and the Visual Imagination* (Cambridge: Cambridge University Press, 2000), p. 2.

creation of a new role for hypothesis.'[5] As Newton's image of the shore on the edge of the ocean of undiscovered truth suggests, knowledge making became much more engaged with uncertainties and the unknown. I believe that this period of scientific history is a particularly rich one for the themes of my study as it offers a range of new types of space being considered as scientific objects or realms of enquiry, as well as examples of engagement with epistemological questions about how and what we can know by those very natural philosophers working at the frontiers of new knowledge.

The scientific subjects of my study — Robert Hooke, Robert Boyle, and Isaac Newton — were all key members of the early Royal Society who worked and published on new spaces and spatialities. In the first chapter of the thesis I consider Hooke's work on microscopy and the sub-visible spaces this revealed; in the second chapter I consider Boyle's work on air and the concepts of invisible and experimental spaces; and in the third chapter, I consider Newton's concepts of absolute and relative space. These three natural philosophers are of particular interest to this thesis because as well as engaging with these spaces as objects of study, they also engage with spatiality both on the page and in the mind, and with questions of epistemology including the role of uncertainty and hypothesis.

As well as considering the work of these three natural philosophers, I also include the poetic work of John Milton. This is not to trace particular scientific theories in Milton's work as many studies have already done, or to assert any biographical connection or direct influence (in either direction) between the Royal Society and Milton — as William Poole's sceptical account demonstrates, the points of contact between Milton and the new scientists do not necessarily equate to non-critical 'engagement' or 'connections' between the two.[6] Rather, I include Milton because he is a poet who engages with the subjects under discussion: the understanding and imagining of space as an object; the use of presentation (in Milton's case rhetorical and figurative effects of language) to evoke different spatialities in the mind of the reader; and epistemological questions about how and what we can know of creation and cause through our creaturely experience. Like Angelica Duran, I believe Milton's literature is 'as much a part of the project that Francis Bacon called the advancement of learning as

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[5] Barbara J. Shapiro, *Probability and Certainty in Seventeenth-Century England: A Study of the Relationship between Natural Science, Religion, History, Law, and Literature* (Princeton: Princeton University Press, 1983), p. 16.

[6] William Poole, 'Milton and Science: A Caveat', *Milton Quarterly*, 38 (2004), 18–34 (pp. 18, 28).

were the optical lenses, air pumps and intravenous syringes created by early modern scientists', and that more than merely recounting or praising the work of natural philosophers, 'literature concerned with the development of knowledge […] participated in a profoundly encompassing cultural project.'[7] I study Milton's poetry alongside the works of Hooke, Boyle, and Newton for what that juxtaposition can reveal of processes of thought, belief, and knowledge-making in all four writers.

The four chapters trace two merging trajectories. The first is a trajectory of object: micro space, invisible space, mathematical space, poetic space. The second is a trajectory of method: observational space, experimental space, conceptual space, imaginative space. The trajectories merge in the third and fourth chapters as the subject and method become nearly congruent. This is not intended to imply any sort of hierarchy or historical progression, but the progression inwards is a deliberate part of my attempt to understand how spatiality, in the context of the practice of studying space as external object, relates to (and possibly affects) the 'inner' spatiality of thought. The trajectories also draw out ways in which these various spatialities and methods speak to one another, for example, the study of micro space has implications for the understanding of invisible space, and the techniques of observational and experimental spaces are recreated in conceptual and imaginative spaces.

In combining the study of understandings of object space(s) with the spatiality of thought, I take my cue from Steven Connor who traces the connection between thinking about things to the act of thinking about thinking, and places a particular importance on certain ambivalent substances, such as air, for this dynamic. Connor is interested in 'the ways in which subjects may be said to be the outcome or achievement of objects'.[8] From this sort of subject/object relation, Connor derives two consequences: first, 'that thinking about thinking can only ever be done through the things that draw, drain and detain our thinking, and that make thinking accessible as a kind of thing', and secondly, 'that thinking about things is unavoidably a kind of thinking about the kind of thing that thinking is.'[9] By examining how early modern thinkers conceived of space as an object, I hope to understand the interior expansiveness of the thinking subject's mind.

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[7] Angelica Duran, *The Age of Milton and the Scientific Revolution* (Pittsburgh: Duquesne University Press, 2007), p. 3.

[8] Steven Connor, 'Thinking Things', *Textual Practice*, 24 (2010), 1–20 (p. 3).

[9] Ibid.

Connor connects these relations to ‘certain thinking things’ whose role it is:

> to embody, not thinking itself, but thinking’s exceeding of every thing, including the things it takes for itself, takes itself for. Certain objects, by failing to capture thought, seem apt to capture its uncapturability. Hence the importance of certain kinds of ambivalent matter and bodiless substance — in particular, air, gas, vapour and their allotropes, […].[10]

Connor uses a suggestive imagery of ‘thinking as a kind of atmosphere’.[11] The spatial effects of these ambivalent substances — for example considering bubbles as things that ‘compound interiority and exteriority’[12] — led me to think about the dynamics of the spatiality of thought in a more abstract way, as distinct from ideas about substances like air or gas, but also about how this abstraction is understood and perceived by means of object relations. As Angela Leighton writes of ‘form’:

> It is an abstraction from matter, removed and immaterial; but it is also subtly inflected towards matter. As a word it holds off from objects, being nothing but form, pure and singular; at the same time, its whole bent is towards materialization, towards being the shape or body of something.[13]

This more abstract idea of space, spatiality, form, is very relevant to the kind of thought that happens at the boundaries of knowledge and in encounters with the unknown. Leighton reminds us that ‘form’ may sometimes refer:

> not to a single boundary line, but to a dividing line, an outline, between different dimensions of understanding. Form, by this account, is not a fixed shape to be seen, but the shape of a choice to be made.[14]

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[10] Connor, ‘Thinking Things’, (2010), p. 12.

[11] Steven Connor, ‘Thinking Things’, (2008), 1–37 <http://www.stevenconnor.com/thinkingthings/> [accessed 8 November 2009] (p. 4): this is an earlier version of the article published in *Textual Practice*.

[12] Connor, ‘Thinking Things’, (2010), p. 14.

[13] Angela Leighton, *On Form: Poetry, Aestheticism, and the Legacy of a Word* (Oxford: Oxford University Press, 2008), p. 1.

[14] Leighton, p. 16.

This idea of form is suggestive of the encounter with the unknown and the ways in which natural philosophers come to understand and to categorize a new object. It perhaps also accounts for the contrast between the expansiveness of mind inherent in Newton's description of himself as a boy on the shore, compared to the shallowness of self possessed by Milton's closed-in reader.

Although Connor's work focuses on the eighteenth and nineteenth centuries, his way of looking at subjectivity and objectivity (the subject as a backformation from the object) has suggestive resonance with the potentially troubled place of the subject in the scientific milieu of the early Royal Society, which sought to be objective in producing empirically valid and testable knowledge in order to create a body of truth gathered from multiple practitioners and external to a solipsistic sense of self, but which also relied on the sensory experience of individual practitioners, and the acts of interpretation that are imbricated in experimental and instrumental seeing, in order to harvest that data. As Patricia Fara describes, 'The more you use elaborate technology the more you need skilled interpretation, so you get more objectivity, but also a much greater layer of subjectivity.'[15] Bronwen Price suggests, 'The object of knowledge is not something which is extractable from those who examine it, but merges with them.'[16] Everything is mediated by the perceiving subject's relation to it and the awareness of this creates a need for the accommodation of more uncertain categories such as probability and hypothesis in early modern knowledge making. As Henry Pollack argues, 'it is *certainty*, rather than uncertainty, that impedes science' and indeed, 'uncertainty is a stimulus that propels science forward.'[17]

By including a consideration of the visual presentation of ideas and data in my thesis, I draw out an often unremarked upon spatial element or stage in the process of developing knowledge. Although the importance of themes from the field of the history of the book has been recognized for the history of science in the early modern period,

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[15] Patricia Fara, 'What You See Depends on How You Look: Time and Space in Scientific Imagery', a talk given at the Royal Institution (London, 10 May 2012).

[16] Bronwen Price, 'Journeys Beyond Frontiers: Knowledge, Subjectivity and Outer Space in Margaret Cavendish's *The Blazing World* (1666)', in *The Arts of Seventeenth-Century Science: Representations of the Natural World in European and North American Culture*, ed. by Claire Jowitt and Diane Watt (Aldershot: Ashgate, 2002), pp. 127–45 (p. 132).

[17] Henry N. Pollack, *Uncertain Science… Uncertain World* (Cambridge: Cambridge University Press, 2003), p. 5.

the emphasis has traditionally been on the role of the text and its contexts in persuading a reader to its content.[18] While persuasive effects are undoubtedly important, I do not believe that they are all that a study of presentation can reveal, or that the relationship of influence between content and presentation only works in one direction. We see this, for example, in Robin Rider's demonstration of how technology and printing practice 'did much to shape the forms of mathematical discourse' in early modern Europe.[19] I locate my work within a critical tradition that studies the scientific illustration as a way of challenging 'the privilege given to theory in the image of science inherited from logical empiricism', and understanding 'the role scientific illustration plays in the creation of scientific knowledge'.[20] This approach seeks to incorporate methods from history of the book and history of art to the understanding of history of science in a way that is much more integrated with epistemology and the making of knowledge rather than just concerned with representation. Wolfgang Lefèvre, Jürgen Renn, and Urs Schoepflin describe a 'dependence' of scientific knowledge on external representations, and list various potencies of images including their ability to 'mediate between practical knowledge and theoretical reflection', or 'to synthesize fragments of knowledge to a global picture, thus providing them with new meaning'.[21]

In this thesis I expand the notion of illustration to cover a wide range of visual instantiations of data, knowledge, or object, including illustrations, tables, diagrams, lists, and other *mise en page* effects. I consider these as visual strategy for ordering, understanding, and working with information. As James Mussel suggests in his book on nineteenth-century astronomy periodicals:

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[18] See for example R. W. Serjeantson, 'Proof and Persuasion', in *The Cambridge History of Science, Vol 3 Early Modern Science*, ed. by Katharine Park and Lorraine Daston (Cambridge: Cambridge University Press, 2006), pp. 132–76 (p. 165). Two key studies operating in this sociological and rhetorical tradition are Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton: Princeton University Press, 1985; expanded edn, 2011), and Bruno Latour, 'Visualization and Cognition: Thinking with Eyes and Hands', *Knowledge and Society: Studies in the Sociology of Culture Past and Present*, 6 (1986), 1–40. I discuss these in detail in Chapter 2.

[19] Robin E. Rider, 'Early Modern Mathematics in Print', in *Non-Verbal Communication in Science Prior to 1900*, ed. by Renato G. Mazzolini (Firenze: Leo S. Olschki, 1993), pp. 91–113 (p. 91).

[20] *Picturing Knowledge: Historical and Philosophical Problems Concerning the Use of Art in Science*, ed. by Brian S. Baigrie (Toronto: University of Toronto Press, 1996), 'introduction', p. 1.

[21] *The Power of Images in Early Modern Science*, ed. by Wolfgang Lefèvre, Jürgen Renn, and Urs Schoepflin (Basel: Birkhäuser Verlag, 2003), 'introduction', pp. vii, viii.

> astronomy is more than observation with the naked eye. In order to work with the stars, they must be translated into a form that can be handled, recorded, moved and compared. Instruments such as telescopes and spectroscopes not only bring the stars closer, they also provide quantifying measures of location and time. […] it is actually these mediating factors that constitute the science.[22]

Like Mussel, I argue that form and mediation are a part of science, and follow his suggestion that, 'For the study of space […] we must turn to the study of spaces, textual and otherwise.'[23]

By considering the visual presentation of science in this way, I include it as a part of the process of knowledge making rather than a subsequent communication of made knowledge. As Stephen Jay Gould asserts, 'Scientific illustrations are not frills or summaries; they are foci for modes of thought.'[24] This emphasis in turn places greater significance on the spatiality of the page as it relates to the ways in which thought is spatial, and to its role in the wider context of new ways of seeing. I build on Lorraine Daston's recent work on early modern weather watching in which she describes the table as a tool for discovery in its function of enabling the practitioner to see.[25]

Furthermore, I integrate my study of visual aspects of the publications under discussion with the study of their content and verbal contexts. The literary approach of my study continues in the vein of established critical attention to the role played by language in the creation of knowledge. As Peter Dear wrote in the early 1990s when it was still only an emerging sensitivity in the history of science, 'language is not simply a transparent medium of communication, but a shaper (perhaps a realizer) of thought and an embodiment of social relations.'[26] Picking up on the suggestiveness of Dear's word

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[22] James Mussel, *Science, Time and Space in the Late Nineteenth-Century Periodical Press* (Aldershot: Ashgate, 2007), p. 27.

[23] Ibid.

[24] Stephen Jay Gould, *Bully for Brontosaurus: Reflections in Natural History* (New York: W. W. Norton, 1991), p. 171.

[25] Lorraine Daston, 'Super-Vision: Weather Watching across Space and through Time at the Early Royal Society and Académie Royale des Sciences', a talk given at the Royal Society conference 'Curiously Drawn: Early-Modern Science as a Visual Pursuit' (London, 21–22 June 2012).

[26] *The Literary Structure of Scientific Argument: Historical Studies*, ed. by Peter Dear (Philadelphia: University of Pennsylvania Press, 1991), 'introduction', p. 4.

'shaper', I combine this linguistic and literary attention with a particular focus on the nuances of spatialilty as expressed and explored through language.

Over the last decade there has been a move within early modern science and literary studies towards an understanding of science and literature as 'functioning as interacting facets of a broadly-defined intellectual culture',[27] and a trend towards looking for overlaps in the ways writers from the two (increasingly considered non-discrete) spheres 'tried to understand — both imaginatively and empirically — the workings of the natural world'.[28] By applying the same interpretive methods and asking the same questions of both scientific and literary texts, I hope that they will speak to each other in a way that promotes a more holistic understanding of the relationship between early modern space and epistemology.

Elizabeth Spiller's work on the constructed nature of knowledge is a key text for this approach to science and literary studies. Her central argument is that:

> science maintains strong affiliations with poetic fictions because, in ways that are rarely acknowledged, its practice emerges out of a central understanding of art as a basis for producing knowledge. A belief in the made rather than the found character of early modern knowledge unites poets and natural scientists.[29]

While I disagree with the implication that there was a conscious awareness of the made quality of knowledge (all of the writers in this study consider themselves to be working to uncover the truths of nature), that engagement with the act of artificial construction is certainly present. As Spiller notes, there is a centrality to artifice in the new science, with instruments such as the telescope and microscope, and even print itself, making it 'possible to discover knowledge but to do so only by means of artifice'.[30] As well as relating to the theme of the role of the visual and the verbal in developing knowledge, Spiller's notion of artificiality connects with my theme of spatiality in the idea of framing. As I shall demonstrate throughout the thesis, the artificial demarcation of

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[27] *Science, Literature and Rhetoric in Early Modern England*, ed. by Juliet Cummins and David Burchell (Aldershot: Ashgate, 2007), 'introduction', p. 6.

[28] *The Arts of Seventeenth-Century Science*, ed. by Jowitt and Watt, 'introduction', p. 5.

[29] Elizabeth Spiller, *Science, Reading, and Renaissance Literature: The Art of Making Knowledge, 1580–1670* (Cambridge: Cambridge University Press, 2004), p. 2.

[30] Spiller, p. 7.

spaces (under a microscope, in a sealed air pump, on a page, in a metaphor, in the conceptual space of a thought experiment) is an important practice for the development of knowledge under the methods of the new science, in particular for aiding a practitioner to be able to see. It is no coincidence that the word *theory* is related to *theatre*.[31]

By combining the study of language in the texts under consideration with the study of their visual aspects and the scientific practices and philosophical theories they discuss, I follow the integrated methods proposed by Sachiko Kusukawa and Ian Maclean. Moving against prior critical traditions that presupposed the relationships between content and context and that studied individual vehicles of transmission separately (e.g. illustrations without text), their book collects together essays that demonstrate 'how words, images, and instruments frequently interact with one another in the same act of transmission'. They propose that this critical move 'has profound consequence for the knowledge transmitted', that it avoids the misinterpretations of disconnected study, and that it can reveal divergent interpretations and receptions by acknowledging tensions between vehicles.[32]

The originality of my study lies in applying this integrated approach of studying content, visual presentation, and verbal exposition together to texts which I read in the contexts of the spatial themes of their content and their author's engagement with questions of perception and epistemology. By doing this, I begin to unlock the relationship between external and internal spatiality, by tracing the processes of thought and imagination in mediating between the experience of the external world and the understanding of it in the mind and on the page.

My thesis starts with a study of Robert Hooke's microscopical investigations, in which he created an observational space within the scope of his lens that revealed by magnification a newly visible world within our existing one, invisible to the naked eye. In Chapter 1, I focus on the ways in which Hooke navigated this new spatiality and traversed the boundaries between the macro and micro worlds, and on the act of interpretive seeing — as opposed to the amanuensis model proposed by Michael Dennis

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[31] *Theory* is derived from the root *θεωρία:* 'a looking at, viewing, contemplation, speculation, theory, also a sight, a spectacle' (*OED*).

[32] *Transmitting Knowledge: Words, Images, and Instruments in Early Modern Europe*, ed. by Sachiko Kusukawa and Ian Maclean (Oxford: Oxford University Press, 2006), 'introduction', pp. 1, 7–8.

— as revealed in his magnificent illustrations and their accompanying descriptions.[33] I also examine Hooke's use of tables, lists, and illustrations in the presentation of his natural historical data, arguing that they are visual and spatial strategies for ordering and grouping thoughts and information in order to produce knowledge.

Robert Boyle's investigations into the properties of air required the creation of an experimental space by means of the air pump in order to partition this invisible and ubiquitous substance that is in some ways synonymous with space itself. In Chapter 2, I consider the ways in which Boyle works on and engages his reader with the invisible air. I explore both his verbal strategies and his choices about what to depict and to not depict in pictures, relating these choices to his epistemological position of nescience, which looks for pattern and order but resists premature systematization. I also read Shapin and Schaffer's concept of 'virtual witnessing' in a different context to their social one of the mustering of assent for hypothesis, contending that it facilitates in the reader the sort of imaginative thinking and mental laboratory necessary for the sort of illative natural philosophy that can understand and think about air.[34]

In Chapter 3, I examine Isaac Newton's concepts of absolute and relative space, considering how we understand space through human experience and how this relates to a conceptual, mathematical understanding of it. I follow Howard Stein and Robert DiSalle in arguing that Newton's absolute space is offered as an epistemological construct required for understanding and working with Newtonian dynamics, rather than posited as an ontological reality, even if there is an abstract sense in which it is more 'true' than its relative counterpart.[35] Furthermore, I argue that absolute and relative space are intimately connected and can only be understood in terms of each other, and that this dynamic traces a similar relation between absolute and relative in Newton's exploration in spatial terms of the nature of God.

In Chapter 4, I consider the work of John Milton and demonstrate the echoes of the experiential, experimental knowledge making (as seen in the Royal Society natural philosophers considered in Chapters 1–3) that are found in Milton's depictions of

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[33] Michael Aaron Dennis, 'Graphic Understanding: Instruments and Interpretation in Robert Hooke's *Micrographia*', *Society in Context*, 3 (1989), 309–64 (p. 323).

[34] Shapin and Schaffer, pp. 23, 25, 60.

[35] Howard Stein, 'Newtonian Space-Time', *The Texas Quarterly*, 10 (1967), 174–200 (p. 197); Robert DiSalle, *Understanding Space-Time: The Philosophical Development of Physics from Newton to Einstein* (Cambridge: Cambridge University Press, 2006), p. 17.

learning and in his epistemological relation of the visible and invisible worlds. I also consider the spatiality of *Paradise Lost*, which offers the reader observational and experimental spaces in the garden of Eden where we observe Adam and Eve and witness their testing, as well as relative and absolute depictions of space as we follow both the astronomical speculations of earth-bound Adam and the cosmic flights of Raphael and Satan as reported by an omniscient narrator. I argue that Milton also explores ideas of place as a psychological function, further emphasizing the importance of relativity in the experience and understanding of space, and contend that Milton's expansive explorations of space and spatiality give the reader a new way of thinking about the invisible and the unknown and help the reader look beyond the creation to the creator.

Chapter 1

Robert Hooke and Micro Space

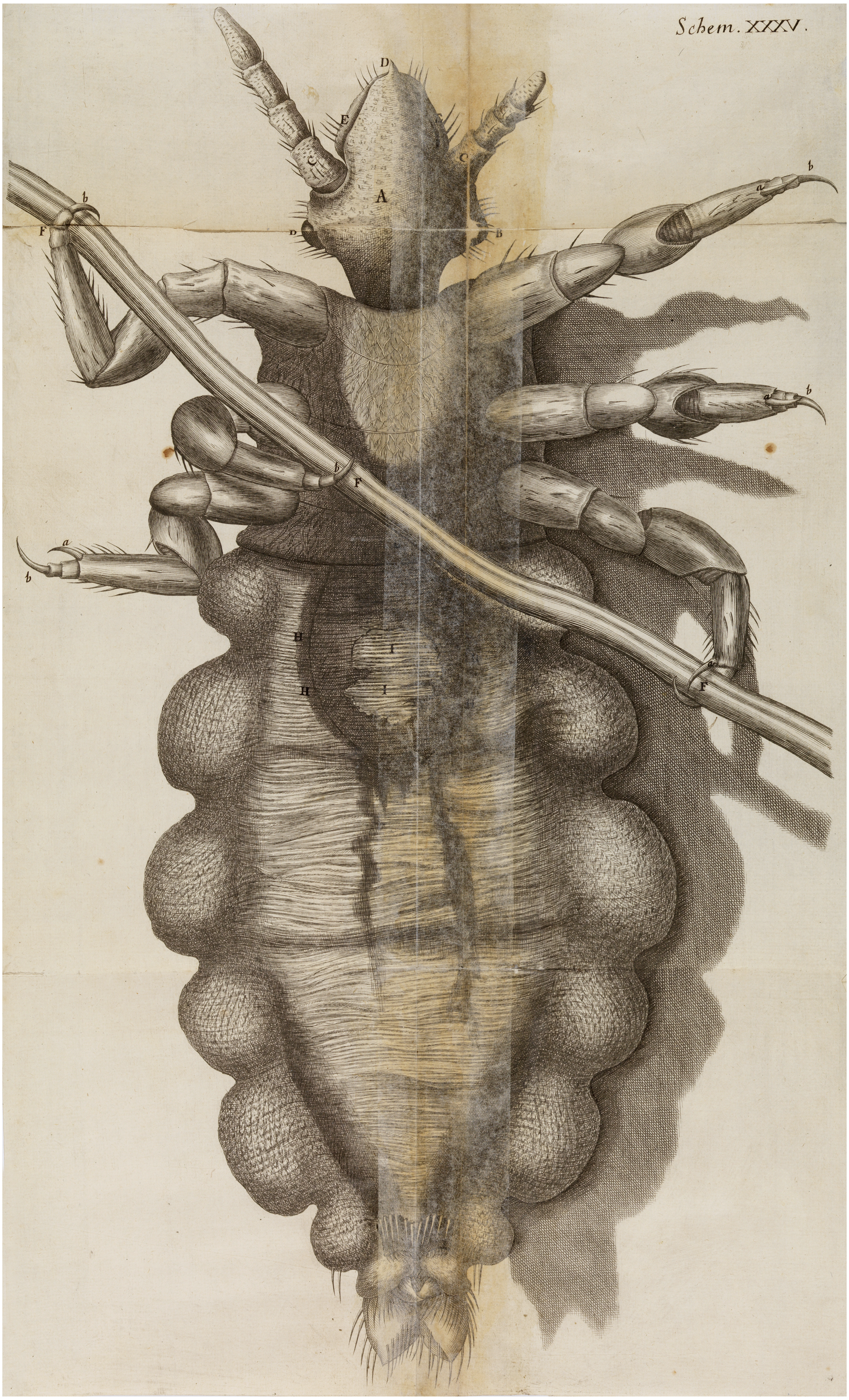

Fig. 1.1. Robert Hooke, *Micrographia* (London, 1665), Scheme 35. Photo: RS.466 © The Royal Society.

Introduction

Hooke's *Micrographia* (1665) is an intensely visual and spatial work. Its thirty-eight engraved plates are unprecedented in extent, detail, and quality, bringing a range of completely new — indeed otherwise inaccessible — sights to his reader.[1] The images speak of deep visual scrutiny in their attention to detail, and of a new understanding of spatiality in their dramatic rescaling of microscopic objects. The head or body louse examined in Observation 54 would have been between 2.1 and 3.6 mm in length (about the size of a sesame seed), however, the magnificent illustration depicting it in Scheme 35 (see Fig. 1.1) is 52 cm long — roughly two hundred times actual size. The level of exaggeration is announced by the fact that, large as the folio volume is, the reader must still unfold the oversized plate to view it. This blowing up of micro space is also found in Hooke's text, which provides lengthy and dense descriptions of these minute objects, including details not visible to the naked eye, such as the louse's outer surface texture or the claws on its feet.

In the preface to the book, Hooke writes of 'a new visible World discovered to the understanding'.[2] The insertion of *visible* into his analogy with the New World highlights the fact that this newly discovered microscopic world is not a new location, but rather a different way of seeing a known one — a new spatialization of the very world 'under our feet' (ibid.). Further, that this new visible world is discovered to the understanding, rather than to the eyes, suggests that this is more than just an expansion of knowledge based on newly visible data. It hints at a more complex relationship between visible data and understanding in Hooke's epistemology. This relationship will be the main theme explored in this chapter as I demonstrate that for Hooke, visuality

[1] *Micrographia* was not the first publication of illustrated microscopical observations — that honour goes to the *Apiarium* of Federico Cesi and Francesco Stelluti, published in Italy in 1625. However, Hooke's is certainly the most impressive and wide ranging of the eleven books on microscopy published in Europe in the forty years since then. For a list of publications see Marian Fournier, *The Fabric of Life: Microscopy in the Seventeenth Century* (Baltimore: Johns Hopkins University Press, 1996), Appendix A.

[2] Robert Hooke, *Micrographia: or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses with Observations and Inquiries thereupon*, (London: Jo. Martyn and Ja. Allestry, 1665), sig. a2^{v} (prefatory material is unpaginated). The 1665 edition is also available as a facsimile reproduction (New York: Dover Publications, 1961). All further references are to this edition and are made parenthetically in the text. I have silently modernized the long s and the spacing around punctuation; otherwise, spelling, punctuation, and emphasis follow the original.

and spatiality were core components of producing knowledge, and that as such, the new world revealed by the microscope was more than just a new object of study, it was inextricably linked to questions of epistemology. In this introductory section, I summarize the epistemology and scientific methodology outlined in Hooke's preface and demonstrate how visuality and spatiality are integral to those systems. This sets the scene for a more detailed consideration in the rest of the chapter of the legibility of nature through Hooke's microscope, of the relationship presented between the micro and macro worlds, and of Hooke's methods of presenting his findings.

The preface to *Micrographia* gives a clear outline of Hooke's epistemology as well as a programme of methodological intent, both of which bear obvious marks of Baconian influence. Hooke describes the prerogative and capacity of mankind to behold the works of Nature and furthermore to consider, compare, alter, assist, and improve on those works — a summary programme of natural history and philosophy with a somewhat utilitarian bent. He acknowledges the limited capacity of fallen man (in Hooke's conception a result of both original sin and man's own culpable choices), but suggests that this might be corrected by post-lapsarian, human means:

> By the addition of such *artificial Instruments* and *methods*, there may be, in some manner, a reparation made for the mischiefs, and imperfection, mankind has drawn upon it self, by negligence, and intemperance, and a wilful and superstitious deserting the Prescripts and Rules of Nature, whereby every man, both from a deriv'd corruption, innate and born with him, and from his breeding and converse with men, is very subject to slip into all sorts of errors. (sig. a1^{r})

Instruments such as the microscope, and indeed the scientific method itself, are seen as potential reparation for human imperfection and error.

More specifically, Hooke writes that the way 'to recover some degree of those former perfections, seems to be, by rectifying the operations of the *Sense*, the *Memory*, and *Reason*' (ibid.). He outlines the various flaws of these faculties and asserts that their remedy 'can only proceed from the *real*, the *mechanical*, the *experimental* Philosophy' (sig. a2^{r}). Hooke thus emphasizes the lack of reality he ascribes to a science *not* grounded in the observation of material things, a preference echoed in his famous comparison between the current state of the science of nature as 'a work of the *Brain* and the *Fancy*' (Bacon's idols of the tribe), and the science to which he urges a return: 'the plainness and soundness of *Observations* on *material* and *obvious* things' (sig. b1^r). The reason he gives for preferring mechanical and experimental philosophy over 'the Philosophy of *discourse* and *disputation*', is that the latter does not pay regard to 'the first ground-work, which ought to be well laid on the sense and memory', whereas the former 'intends the right ordering of them all' (sig. a2^r).

Hooke prescribes the methods he believes will counter the effects of our flawed faculties. Regarding the senses, he encourages 'a *watchfulness over the failings* and an *inlargement of the dominion,* of the Senses' and also 'a supplying of their infirmities with *Instruments*' (ibid.). To remedy the ailing memory Hooke recommends the careful recording of observations, and hints at a particularly useful 'manner of compiling a Natural and Artificial History' (sig. b1^v) comprising of tables. To remedy the understanding, Hooke suggests comparison, scrutiny, and consideration: 'nothing is to be *omitted*, and yet every thing to pass a *mature deliberation*' (ibid.). He also urges the ordering of the other faculties by the understanding so that the whole system operates smoothly.

It is tempting to read Hooke's preface as claiming to offer a perfect remedy for the cognitive weaknesses of man. Indeed critics often interpret without question the line, 'a *sincere Hand*, and *a faithful Eye*, to examine and to record, the things themselves as they appear' (sig. a2^v), as an expression of presumed access to truth; Michael Dennis even describes Hooke as 'not so much an observer as the microscope's amanuensis'.[3] However, there is an important potential contingency in the phrase, 'as they appear'. Hooke admits the potential for human imperfection into his remedy and indeed his method for developing knowledge. He believes that the defects of fallen man are redeemable, but this is no magical restoration; the aim of repairing the faculties is 'to recover *some degree* of those former perfections' (sig. a1^r, my emphasis). Hooke's method includes 'a *watchfulness over the failings* […] of the Senses'. It is the admission of and watchfulness for their failings — rather than the removal of the cause of their failure — that is remedy for the senses. This is reiterated in the instruction for the understanding to order the lower faculties as a lawful master rather than a tyrant: 'It must *watch* the irregularities of the Senses, but it must not go before them, or *prevent* their information' (sig. b2^r).

[3] Dennis, p. 323.

The method is to gather observational data as accurately as possible, and indeed as much of it as possible, Hooke being proud to contribute to 'the large stock of *natural Observations*, which so many hands are busie in providing' (sig. b1^{r}). The next step is to apply methods of judgement in considering this data. Hooke addresses the dilemma in trying to remedy the understanding:

> least by seeking to inlarge our Knowledge, we should render it weak and uncertain; and least by being too scrupulous and exact about every Circumstance of it, we should confine and streighten it too much. (sig. b1^{v})

To resolve the dilemma between credulity and scepticism, he resolves that, 'In both these the middle ways are to be taken' (ibid.). All data is to be admitted, but must then be subject to 'mature deliberation':

> all to be so *severely examin'd*, that there remain no room for doubt or fallibility; much *rigour* in admitting, much *strictness* in comparing, and above all, much *slowness* in debating, and *shyness* in determining, is to be practised. (sigs b1^{v}– b2^{r})

There is no perfect certainty with this method, but by committing to best practice in the gathering of data — a hesitancy in determining fact and the exercise of collaborative social controls such as comparison of results and lengthy debate — a reliable body of knowledge is possible.[4] As well as utilizing the social controls provided by his immediate community, Hooke also highlights the temporary nature of the knowledge he is producing, offering it up to be refined or superseded by the wider scientific community and by later generations. He asks the reader, 'not absolutely to rely upon these Observations of my eyes, if he finds them contradicted by the future Ocular experiments of sober and impartial Discoverers' (sig. b1^{r}).

In a similar vein, Hooke comments on the uncertainty of any seeming conclusions he makes:

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[4] Hooke's approach is more in line with what Richard H. Popkin describes as 'constructive scepticism' in *The History of Scepticism from Erasmus to Descartes* (New York, 1961).

> If therefore the Reader expects from me any infallible Deductions, or certainty of *Axioms*, I am to say for my self, that those stronger Works of Wit and Imagination are above my weak Abilities; […] Wherever he finds that I have ventur'd at any small Conjectures, at the causes of the things that I have observed, I beseech him to look upon them only as *doubtful Problems*, and *uncertain ghesses*, and not as unquestionable conclusions, or matters of unconfutable Science. (sig. b1^{r})

Hooke's conjectures are to be read as '*doubtful Problems*' and '*uncertain ghesses*'. However, despite Hooke's apparent humility, the 'Works of Wit and Imagination' are simply a recasting of the 'work of the *Brain* and *Fancy*' and thus the infallible deductions and certain axioms the reader might expect are not really desirable or credible elements of Hooke's method. Contingent hypotheses are preferred and it is the contingency with which Hooke frames them that allows him to admit such conjectures into his work. He admits uncertainty without rendering knowledge thus uncertain. The embracing of conjecture goes beyond the usual remit of the Royal Society's sanctioned approach and indeed, in a separate prefatory note to the Society, Hooke apologizes for this and publicly distances his approach from theirs. Hooke acknowledges that in *Micrographia* 'there may perhaps be some *Expressions*, which may seem more *positive* then YOUR Prescriptions will permit', referring to the Society's rule against 'the *espousal* of any *Hypothesis* not sufficiently grounded and confirm'd by *Experiments*', and confirming that he intends these expressions to be 'understood only as *Conjectures* and *Quaeries*' (sig. A2^{v}).

In summary, Hooke believes that man has a capacity for natural knowledge with the help of instrumental and methodological correctives. However, this is not a perfect antidote to man's weaknesses and Hooke's methods reflect that, accommodating man's imperfections with various checks to mitigate against potential error and with the admission of the contingency of human knowledge. Hooke's approach to true knowledge is very much by means of a process of the refinement of imperfect knowledge. As Lotte Mulligan observes, for Hooke 'it was possible to reach the most complex problems by an incremental increase in knowledge'.[5]

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[5] Lotte Mulligan, 'Robert Hooke and Certain Knowledge', *Seventeenth Century*, 7 (1992), 151–69 (p. 156).

With the general emphasis on observation and sensory data within Hooke's method, and the specifically visual nature of observation which the use of the microscope privileges in *Micrographia*, there is an obvious visual bias to the practical elements of these instances of knowledge development. However, it is my argument that visual and spatial elements are more fundamental to Hooke's philosophy, and I believe that this is a result of the central importance of proportion and organization to Hooke's epistemology and method.

When Hooke describes the flaws in the faculties of sense, memory, and understanding or reason, he figures them as problems of proportion, of physical reception, and of organization. The 'infirmities of the Senses' are the result of 'the *disproportion of the Object to the Organ*' or from '*error in the Perception*, that many things, which come within their reach, are not received in a right manner' (sig. a1^{v}). The problems with memory are expressed by metaphors of location, which indicates the importance of their spatial organization: 'we often let many things *slip away* from us [...] or [become] so *overwhelmed* and buried under more frothy notions, that when there is need of them, they are in vain sought for' (ibid.). The faults of reason are also cast in terms of proportion: 'for the limits, to which our thoughts are confind, are small in respect of the vast extent of nature it self; some parts of it are *too large* to be comprehended, and some *too little* to be perceived' (ibid.). Proportion does not necessarily refer to spatial proportion (Hooke discusses senses other than sight) but when he discusses mental processes he defaults to spatial and visual metaphors, here considering objects of nature as *too large* or *too little*. The close association of comprehension and perception exhibited here is also significant and (together with the emphasis on the senses elsewhere in the preface) makes sensory perception a part of understanding, not just a preliminary to it.

The spatial metaphor for the mental organization of the memory reveals that Hooke thinks about his own processes of thought in spatial terms. This goes further and Hooke casts spatiality as something useful; in his remedy for a disorganized memory he urges the 'ranging and registring its [natural history's] Particulars into Philosophical Tables, as may make them most useful for the raising of *Axioms* and *Theories*' (sig.

b1^{v}). For Hooke, spatial organization is a tool of thought, and as Nick Wilding observes, *Micrographia* has an apparent ‘obsession with questions of order’.[6]

In this chapter I build on my initial reading of the preface to demonstrate the ways in which visuality and spatiality play a significant role in Hooke’s understanding of thought and in his methodology for developing knowledge as shown in *Micrographia* and his wider works. I do this by exploring three key themes. In the first section, on the legibility of nature, I consider the disparity between what is sought by means of the microscope and what is actually revealed, and the relationship between the visible, exterior surfaces of nature and the secret, inner workings Hooke aspires to understand. In the second section, on the relationship between the macro and the micro worlds, I examine how Hooke uses analogy, metaphor, and the relationship between known and unknown to explore new knowledge. In the final section, on the presentation of data, I look at Hooke’s visual strategies, including illustration and the assemblage of data in tables, as methods for developing knowledge. I also consider how this method is mirrored in his theories of mental processes such as memory.

The Legibility of Nature

In this section, I consider the tension between the access to interiority natural philosophers hoped the microscope would provide, and the granularity it actually offered — a tension intimately connected to the relationship between vision and understanding. Hooke shares in this frustration, but utilizes methods — both of observation and epistemology — to ensure that some degree of knowledge (albeit incremental and contingent) is attained.

The natural philosophers of the *Accademia dei Lincei* were Hooke’s precursors in microscopical science. The mythological figure Lynceus, from whom they took their name, was one of the Argonauts and had telescopic eyesight and a glance that penetrated matter. However, as Cristoph Lüthy demonstrates, while the telescopic aspect was interpreted literally, the penetrative aspect of Lynceus’s gaze was considered

[6] Nick Wilding, ‘Graphic Technologies’, in *Robert Hooke: Tercentennial Studies*, ed. by Michael Cooper and Michael Hunter (Aldershot: Ashgate, 2006), pp. 123–34 (p. 125).

by the *Lincei* to be metaphorical.[7] Stelluti wrote that Prince Cesi chose the lynx as emblem of their academy, 'to remind us of the acuteness of vision, not of the corporeal eyes, but of the mind, necessary [...] to penetrate the inside of things'.[8] Lüthy points out that the *Persio tradotto*, in which these words appear, also contains some of the first microscopical illustrations but does not connect microscopy with the Lyncean penetration of the 'inside of things', concluding that 'neither Cesi, nor Stelluti understood "internal" and "external" as references to spatial, material, and therefore visualizable arrangements'.[9]

However, Hooke's reference to Lynceus (and indeed the Lynceans) in the Horatian couplet quoted on the title page of the *Micrographia* is rather more ambiguous. The quotation reads, '*Non possis oculo quantum contendere Linceus, | Non tamen idcirco contemnas lippus innungi.*' (If you were/are not able to stretch as far as Lynceus with your eyes, nevertheless, you would not for that reason, having swollen eyes, scorn to anoint them.) The idea of anointing swollen eyes acts as a metaphor for limited human vision aided by the corrective salve of the microscope. The verse seems to encourage human efforts to see further and to validate the ideas (also encountered in the preface) of utilizing man-made helps in this endeavour, and of the value of even limited (and thus contingent and incremental) sight. Just because we do not have Lyncean vision does not mean that we should not try to improve what we do have. Although it is framed as a negative, the subjunctive *Non possis* (as opposed to the indicative *non potes*) entertains the hypothetical idea of the reader seeing as far as Lynceus and so puts the other degrees of vision (unassisted and microscopical) into a spectral relation with perfection at one end, rather than a binary relation of perfect/flawed vision or even seeing/not seeing. By referring to Lynceus's telescopic gaze on the title-page of a book of microscopy, Hooke also brings into contact the literal and metaphorical aspects of hyper-perception, Lynceus's enhanced vision with the penetrative capacity of the mind, and perhaps implies that the microscope facilitates both penetrative vision and penetrative understanding. This suggestion matches the corpuscularian confidence that the inner workings of things are empirically knowable.

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[7] C. H. Lüthy, 'Atomism, Lynceus, and the Fate of Seventeenth-Century Microscopy', *Early Science and Medicine*, 1 (1996), 1–27 (pp. 7–9).

[8] Francesco Stelluti, *Persio tradotto in verso sciolto e dichiaroto* (Rome: Giacomo Mascadi, 1630), p. 37, quoted in translation in Lüthy, 'Seventeenth-Century Microscopy', p. 8.

[9] Lüthy, 'Seventeenth-Century Microscopy', p. 9.

There seems to have been a hope that with the aid of the microscope, vision could be literally as well as metaphorically penetrative. Fournier and Lüthy have both argued that the rise of the microscope corresponds to the rise of mechanical or corpuscularian philosophy in the 1660s due to the belief that the microscope would reveal the finer texture of atomic structure.[10] But by February 1692, Hooke in his 'Discourse Concerning Microscopes and Telescopes' complains of the 'Neglect and Slighting' of serious microscopical study, 'now reduced almost to a single Votary, which is Mr. *Leeuwenhoek*; besides whom, I hear of none that make any other Use of that Instrument, but for Diversion and Pastime'.[11] Fournier warns against the oversimplification of the rise and fall model and highlights the tendency for scholars to ignore eighteenth-century work and/or microscopical studies of less relevance to mechanical philosophy. However, she also notes that while microscopical discoveries initially seemed to support the mechanical explanation by revealing finer structures, the operation of the 'finely woven fabric of organic matter' revealed under the lens did not actually correspond with mechanical actions, and that consequently other theories, such as that of capillary vessels, came into vogue. These new theories were confirmed by existing microscopical data and so did not require further investigation.[12] Lüthy implicates the new conception of space — the victory of Newtonian mechanics over the 'visual reductionism of corpuscularian physics' — in the relegation of microscopy to its marginal, eighteenth-century status.[13] Both accounts agree that the microscope failed to reveal a fine enough texture to prove the corpuscularian thesis.

The accounts of the rise and fall of microscopy offered by Fournier and Lüthy presume a positivist philosophy of science, which demands absolute certainty in its explanations. Hooke's epistemology, however, although empirically based, allows room for information with a greater degree of uncertainty to be a contingent part of an incremental knowledge. It also relies on the vision and understanding operating in more integrated ways to achieve penetration of the objects studied. As such, while frustration with the limits of microscopy is evident in *Micrographia*, it is not the full story.

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[10] Fournier, pp. 4, 197; Lüthy, 'Seventeenth-Century Microscopy', p. 16.

[11] Robert Hooke, *Philosophical Experiments and Observations*, ed. by W. Derham (London: Frank Cass, 1967), p. 261.

[12] Fournier, pp. 6, 197.

[13] Lüthy, 'Seventeenth-Century Microscopy', p. 25.

In Observation 18, ‘Of the *Schematisme* or *Texture* of *Cork*, and of the Cells and Pores of some other such frothy Bodies’, Hooke, judging from the weight and pliability of Cork, anticipates that ‘certainly the texture could not be so curious, but that possibly, if I could use some further diligence, I might find it to be discernable with a *Microscope*’ (pp. 112–113). He carefully prepares his sample and is rewarded with the sight of ‘the first *microscopical* pores I ever saw, and perhaps, that were ever seen’ (p. 113). The spectacle is not all he apprehends though; he writes, ‘I no sooner discern’d these [...] but me thought I had with the discovery of them, presently hinted to me the true and intelligible reason of all the *Phaenomena* of Cork’ (ibid.). Hooke, basing his analysis on sensory information about cork at the macro level, anticipates the ability of the microscope to reveal that substance’s ‘texture’. On seeing the microscopic pores, he has an instantaneous understanding of cork and its phenomena, a revelation of truth whose immediacy (‘no sooner discern’d’, ‘the discovery of them presently hinted’) suggests an intimate relationship between the vision of microscopic structures and knowledge or understanding of them.[14] However when he goes on to list a series of questions and answers about the properties of cork using the hints suggested by the view in the microscope, this relationship is found to be more complex as his answers bear less and less certainty and go from being immediately discernable of the visible evidence to being more speculative and interpretive.

The solution to the first query — why cork is so light — is immediately and visually discernible: ‘my *Microscope* could presently inform me’ (ibid.). The second enquiry — why cork does not take in water and air (for example, when floating on water) — has a slightly more laboured explanation derived from what can be seen of the microscopic pores but also relying on a certain amount of deductive reasoning: ‘since our *Microscope* informs us […]. It seems very plain […], since […], and consequently’ (ibid.). The third enquiry — why cork is springy and returns to shape when compressed — is based on visual examination and on further ‘divers trials’ (p. 114) of this act of compression. However, these trials yield only a circular explanation as Hooke finds that cork ‘consists of an infinite company of small Boxes or Bladders of Air [i.e. pores], which is a substance of a springy nature, and that will suffer a considerable

[14] From context it is clear that *presently* is here used in the original sense, common in the period, of ‘without delay’ or ‘immediately’ (*OED*, 1a), rather than the current usage of ‘soon’ (*OED*, 1b), which is dubious before c. 1650.

condensation' (ibid.). This observation is apparently not satisfactory as an explanation, and Hooke recourses to speculation about the substance at an even more microscopic level (beyond the reach of Hooke's contemporary technology): 'besides, it seems very probable that those very films or sides of the pores, have in them a springing quality' (ibid.). Even though the observation is entirely new to natural history and in itself would be an interesting and valuable contribution, Hooke has an urge to explain — to seek and find, or at least hypothesize — the hidden causes behind observable phenomena, even when those reasons are not visibly or immediately discernible. This desire to push beyond the limits of visibility may also explain his metaphorical use of the word *infinite* to describe the number of 'Boxes or Bladders'.

Hooke, following from his three enquiries, digresses into a discussion of the potential power of the microscope to reveal the finer texture the corpuscularians sought, revealing his frustration that the technology is not yet able to fulfil that potential:

> And could we so easily and certainly discover the *Schematisme* and *Texture* even of these films [the sides of the pores], and of several other bodies, as we can these of Cork; there seems no probable reason to the contrary, but that we might as readily render the true reason of all their *Phenomena*; as namely, what were the cause of the springiness, and toughness of some, both as to their flexibility and restitution. [...] But till such time as our *Microscope*, or some other means, enable us to discover the true *Schematism* and *Texture* of all kinds of bodies, we must grope, as it were, in the dark, and onely ghess at the true reasons of things by similitudes and comparisons. (p. 114)

Hooke — a committed empiricist and corpuscularian philosopher — is looking for the *true reason* of phenomena (i.e. an explanation of its cause) in visible matter. He believes that better optical technologies will reveal an underlying structure of particles whose size and shape will provide this explanation and that in the meantime we must use similitudes and comparisons to guess at those reasons. Hooke repeats the phrase '*schematism* and *texture*', the first use seemingly with sole reference to the material and to what can be seen visibly (with a strong enough microscope), and the second somewhat more ambiguously as the 'true *Schematism* and *Texture* of all kinds of bodies'. It is unclear whether this refers to a precise microscopical view or a more Platonic, axiomatically 'true', and indeed universal schematism and texture, that is, a secret knowledge of nature. This potential double meaning creates a more complex interrelation between vision and understanding. The term is found throughout the observation, concatenated by repeated mental zooming with a hypothetically more and more powerful microscope. Hooke finds the observable schematism and texture of Cork, then hypothesizes about finding the schematism and texture of this texture itself, and so on until a 'true' schematism and texture of bodies is found. Being 'as it were' in the dark gives an element of metaphoricity to the condition of visibility for knowledge and thus the necessary visibility of this true texture. This both highlights the corpuscularian problem of basing one's ability to know the world on the vision of something that as yet cannot (and perhaps may not) be seen, and also provides a temporary solution to scepticism by offering a way to hypothesize the phenomena based on 'similitudes and comparisons'.

In a similar passage in the preface, Hooke writes:

> It seems not improbable, but that by these helps [i.e. lenses] the subtilty of the composition of Bodies, the structure of their parts, the various texture of their matter, the instruments and manner of their inward motions, and all the other possible appearances of things, may come to be more fully discovered; […]. From whence there may arise many admirable advantages, […] because we may perhaps be inabled to discern all the secret workings of Nature, almost in the same manner as we do those that are the productions of Art. (sig. a2^{v})[15]

Again, Hooke expresses a belief in (and desire for) the microscope's potential to reveal corpuscularian truths visibly and man's ability to understand causality ('the secret workings of Nature') based on mechanical principles (i.e. by analogy with 'productions of Art'). The understanding of causality is presented as a likely result of visual data at the right level of magnification. However, it is important to note Hooke's careful wording; the 'true Reason' in the previous extract and 'the secret workings of Nature' in this, are probable, not necessary, results of microscopic vision. In particular the idea that we may 'perhaps be inabled to discern' leaves a subtle amount of room for the possibility that microscopic vision will not reveal nature's secrets, and also for the

[15] The theme of the 'inward Texture and Constitution' of bodies also recurs in Hooke's long essay, 'A General Scheme, or Idea of the Present State of Natural Philosophy'. See Robert Hooke, *The Posthumous Works of Robert Hooke*, ed. by Richard Waller (London: Sam Smith and Ben J. Walford, 1705), p. 3.

structural separation of the two stages of this knowledge production — discovering the appearances of things and then discerning their secret workings. This again speaks of a more complex relation between seeing and knowing, which requires an interpretive stage, than the ideas of Hooke as the microscope's amanuensis (admittedly suggested by some of his own rhetoric) might suggest. The fact that the discernment of secrets of nature occurs '*almost* in the same manner' (my emphasis) as the discernment of the familiar productions of art, also admits some degree of interpretation and approximation.

The sense that increased vision might be simultaneously literal and metaphorical is present in other early encomiums to the potential revelatory power of the microscope. Henry Power writes,

> If the Dioptricks further prevail [...] we might hope, ere long, to see the Magnetical Effluviums of the Loadstone, the Solary Atoms of light [...] the springy particles of Air, the constant and tumultuary motion of the Atoms of all fluid Bodies, and those infinite, insensible Corpuscles (which daily produce those prodigious (though common) effects amongst us).[16]

The atoms of light, springy particles of air, and atoms of fluid bodies are all given a sense of materiality or tangibility. However, corpuscles themselves are described as 'infinite' and 'insensible', even while Power claims the possibility of seeing them. Similarly the insubstantial particles are associated with motion and substance while the corpuscles are associated with abstract causality, making corpuscles seem a philosophical rather than material reality.

John Henry observes that whenever Hooke has recourse to hypothetical concepts beyond the reach of the senses, Hooke claims he can, 'make the existence of this concept probable by analogy with experimentally amenable phenomena', and when discussing methodology, Hooke 'always emphasises the usefulness of experimentation for establishing the behaviour of "secret", "subtle", "abstruse", and "hidden" principles of nature'.[17] However, Henry overstates his case when he argues that the mechanical or

[16] Henry Power, *Experimental Philosophy, In Three Books* (London: T. Roycroft, 1664), fols c2^{v}–c3^{r}. Quoted in Fournier, p. 93.

[17] John Henry, 'Robert Hooke, The Incongruous Mechanist', in *Robert Hooke: New Studies*, ed. by Michael Hunter and Simon Schaffer (Woodbridge: The Boydell Press, 1989), pp. 149–80 (p. 163).

corpuscularian philosophy was more occult than Aristotelian philosophy because of its reliance on the occult behaviour of invisible and insensible particles.[18] The attention Henry draws to the inclusion of uncertainty in Hooke's epistemology is much more adequately explained by his openness to metaphor and conjecture as tools of thought in a wider programme of knowledge, than a philosophy of natural magic.

There seems to be a fundamental disconnect between what the microscope can offer and what many microscopists, and even historians of microscopy, want it to offer. Brian Ford, comparing microscopes and telescopes, writes:

> Telescopes maintain our remoteness from the Universe, whereas microscopes let the observer penetrate the recesses of life, peer at atoms and molecules, watch the processes of living organisms, and discern the hidden nature of humankind. Telescopes hold you up to a window, microscopes open doors and invite you to explore within.[19]

According to Ford, the microscope does allow for that second penetrative aspect of Lyncean sight, and his list aligns views of atoms with the discernment of a 'hidden nature' and the idea of exploring 'within'. However, he is missing a step. The microscope allows scientists to see smaller, finer surface detail, that is to see with a higher level of granularity, but this does not necessarily imply access to interiority — either literal or, like Hooke's 'inward texture', somewhat metaphorical — however much this is desired (as Gaston Bachelard observes, 'an empty drawer is *unimaginable*').[20] Interiority is frustratingly elusive to the microscopist.

Margaret Cavendish repeatedly berates the microscopists for their mistaken assumption that the instrument offers them access to the interior of things, parodying

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[18] Henry, p. 169. Cf. Mark E. Ehrlich, 'Mechanism and Activity in the Scientific Revolution: the Case of Robert Hooke', *Annals of Science*, 52 (1995), 127–51, who counters these 'revisionist' claims for the presence of natural magic and active principles in Hooke's work by Henry and others, finding Hooke to be a purely mechanical philosopher.

[19] Brian J. Ford, 'The Royal Society and the Microscope', *Notes and Records of the Royal Society*, 55 (2001), 29–49 (p. 29). He makes a similar claim in Brian J. Ford, *Images of Science: A History of Scientific Illustration* (London: The British Library, 1992), p. 167: 'Only the microscope takes us *within* worlds we cannot otherwise know' (my emphasis).

[20] Gaston Bachelard, *The Poetics of Space*, trans. by Maria Jolas (Boston: Beacon Press, 1969), p. xxxvii.

Hooke's methods in her *Description of a New World Called the Blazing-World* (1666). Mary Baine Campbell, in exploring the submicroscopic and interior worlds of Hooke and Cavendish respectively, upholds Cavendish's assessment, claiming that while Hooke investigates interiors, his optical instrument deconstructs the very notion of interior, and all it finds is further surfaces.[21] Campbell compares Cavendish's interest in the immaterial interior of the person and her sense that the immaterial and unverifiable were losing status as objects of knowledge, with Hooke's material gaze and the 'cyber-certainty of instrument-based (prosthetic) perception'.[22] Campbell highlights the almost fetishistic act of objectification that takes place in Hooke's examination of the head of the dead drone fly in Scheme 24 (see Fig. 1.2), describing the striking foldout plate as 'hyperbolically visible, hyperbolically blind at once'.[23] She writes that Hooke's examination of the eye, while emphasizing the mechanism of vision, 'manages only to convey a sense of the surface beneath surface, each of them reflecting back to the unexamined eye of the *scientist* an image of himself and his own domestic "interior"' (ibid.). The somewhat sinister irony of the examination of a dead eye, which no longer sees but only reflects the surroundings, turns the eye into a surface and robs it of its interiority.[24] John Locke also complains that the microscope reveals nothing but surfaces:

> Poreing and gazeing on the parts which we dissect without perceiving the very precise way of their working is but still a superficial knowledg, and though we cut into there [*sic*] inside, we see but the outside of things and make but a new superficies for ourselves to stare at.[25]

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[21] Mary Baine Campbell, *Wonder and Science: Imagining Worlds in Early Modern Europe* (Ithaca: Cornell University Press, 1999), p. 182.

[22] Campbell, pp. 182–83. It is also a concern of Campbell's paper that this prosthetic perception was one to which women in particular had little or no access.

[23] Campbell, p. 198.

[24] Cavendish, who parodies Hooke's description of the drone fly with a blazon on her Empress's dress, switches the viewpoint and identifies with the eye beneath the microscope, and not the eye behind the gaze. See Campbell, p. 213.

[25] John Locke, attr., 'Anatomie' fragment (1668), quoted in Anne-Julia Zwierlein, 'Queen Mab under the Microscope: The Invention of Subvisible Worlds in Early Modern Science and Poetry', in *Spatial Change in English Literature*, ed. by Joachim Frenk (Trier: Wissenschaftlicher Verlag, 2000), pp. 69–97 (p. 73).

Locke highlights the fact that the interiority sought was something more than just the interior of bodies. Even when practitioners dissect and 'cut into there inside', they still only see outsides, succeeding only in making new surfaces. This in turn frustrates knowledge production; as Zwierlein notes, Locke, 'expresses his epistemology in spatial terms: "superficies" and "superficial knowledg" are synonymous'.[26]

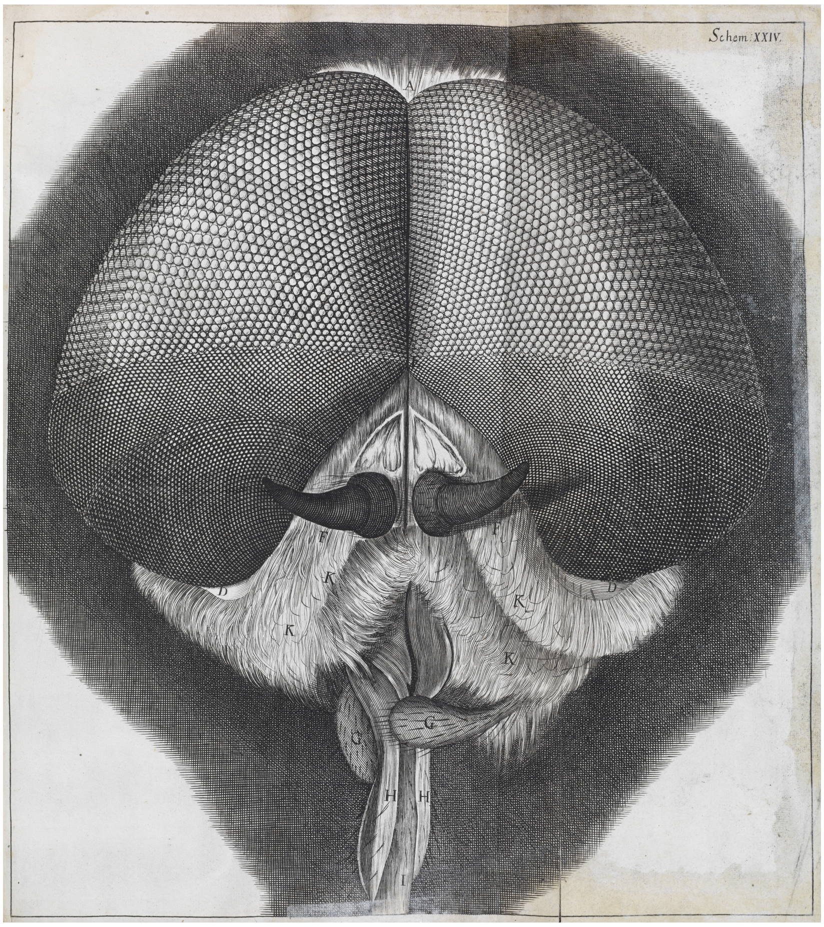

Fig. 1.2. Robert Hooke, *Micrographia* (London, 1665), Scheme 24. Photo: RS.1885 © The Royal Society.

As shown above, Hooke's search for the inner texture of cork is frustrated, despite his various acts of dissection.[27] There is a similar tension in Scheme 7 where there is a striking contrast between Hooke's illustration of the gravel found in his urine — what he saw through the microscope — and his speculative diagrams of the atomic

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[26] Zwierlein, p. 73.

[27] See *Micrographia*, Scheme 11, Fig. 1 for cross and longitudinal sections, and p. 115 for the accompanying description.

alignment of crystalline structures (discussed below) — the interiority he was actually seeking (see Fig. 1.4).[28] Before the accompanying description in the preface is read (sig. f1^{v}), even Hooke's illustration of the interior of the microscope, Figure 4 in Scheme 1, is not obviously a cross section of an internal part of the compound microscope shown in Figure 6, rather than an exterior view of a different piece of apparatus (see Fig. 1.3). Surfaces prove themselves to be fractal in nature, and interiority an ever-retreating concept.

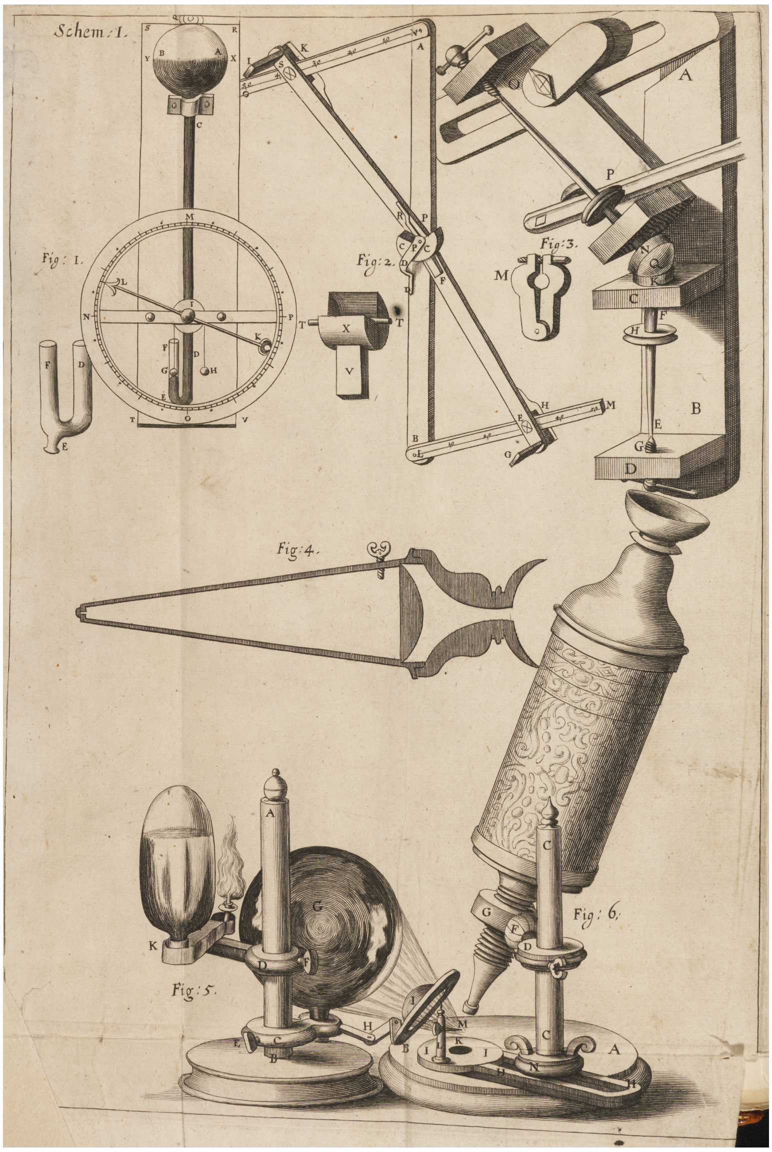

Fig. 1.3. Robert Hooke, *Micrographia* (London, 1665), Scheme 1. Photo: RS.1871 © The Royal Society.

[28] Hooke was fascinated by and highly aware of what went into and out of his body, an instinct that I believe echoes this desire for knowledge of interiors. See Lisa Jardine, *Ingenious Pursuits: Building the Scientific Revolution* (London: Little Brown, 1999), p. 296.

The contextual relation of interiority and exteriority seems to be important. The act of looking at something under a microscope or looking at an illustration of a microscopic subject, has a different effect to witnessing, for example, a dissection or looking at anatomical illustrations, even in cases where that microscopic subject has been dissected. Macro level dissections or experiments (such as the gruesome experiment into respiration which Hooke performed on a live dog in 1664), and strange phenomena such as Hugh Montgomery's chest, allow the context of the exterior body to be preserved.[29] Similarly, anatomical illustrations, such as those of Vesalius, show the interior of the body in the context of the whole body, the interior being revealed by the peeling back of flaps of skin. This preservation of the exterior context signals the transgression of a threshold and thus creates a sensation of interiority to what is witnessed. Microscopic views or illustrations, by contrast, do not preserve this distinction and by adjusting his or her gaze to the microscopic level, the reader instead creates new exteriors. The threshold becomes one of optical power, the threshold between the macro and micro views, which is different to the threshold between the exterior and interior of the body. Simply viewing an object through a microscope, that is, viewing a surface at a higher granularity, is not enough to cross the threshold into interiority.

However, Hooke does manage to gain some access to interiors in certain instances where he is able to see through the transparent body of his subject to observe interior organs. The resulting illustrations, such as the water gnat of Scheme 27 and the louse of Scheme 35 (see Fig. 1.1), preserve the context of the intact exterior of the insect at the same time as depicting its shadowy innards through the transparent exterior. They are reminiscent of the illustrations of the veins in the forearm shown through the transparent skin in William Harvey's *De Motu Cordis* (1628), and — as with Harvey's study of the circulatory system — one of the advantages of this view of insects is the ability to witness live movement. In writing of this method of viewing in his study of the water gnat (Observation 43), Hooke acknowledges some of the tensions inherent in other methods of scientific observation:

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[29] Hugh Montgomery (1623–1663) was an Irish peer who received an injury in childhood that left him with a permanent hole in his side that he covered with a metal plate and through which his heart could be seen. Both Charles I and William Harvey witnessed this phenomenon and Montgomery even allowed them to touch his beating heart.

> I could perceive, through the transparent shell, while the Animals surviv'd, several motions in the head, thorax, and belly, very distinctly, of differing kinds, which I may, perhaps, elsewhere endeavour more accurately to examine, and to shew how great benefit the use of a *Microscope* may be for the discovery of Nature's course in the operations perform'd in Animal bodies, by which we have the opportunity of observing her through these delicate and pellucid teguments of the bodies of Insects acting according to her usual course and way, undisturbed, wheras, when we endeavour to pry into her secrets by breaking open the doors upon her, and dissecting and mangling creatures whil'st there is life yet within them, we find her indeed at work, but put into such disorder by the violence offer'd, as it may easily be imagin'd how differing a thing we should find, if we could, as we can with a *Microscope*, in these smaller creatures, quietly peep in at the windows, without frightening her out of her usual byas. (pp. 185–86)

Hooke's description of such processes undertaken in the preparation of many microscopic samples (including Hooke's own) as mangling, violent, and disordering to nature, reflect both the unseemliness of acts such as dissection, and the scientific uncertainty they produce. As well as dissection, other preparatory techniques — boiling, macerating, or injecting with substances such as wax, gypsum, or ink — were used to help counter the difficulties of conducting microscopical observations on animal tissue, in particular the difficulty of rendering it and its features visible under the microscope.[30] However, practitioners were concerned about the veracity of their observations under such conditions as they suspected their samples were being changed from their natural state by this very processing ('how differing a thing we should find').[31] Hooke seems to find a valuable compromise in insects whose transparent bodies allow for observation without this disruption to the usual course of nature. In contrast with the urge to dissect and anatomize, Hooke is sometimes able to see more, and see more faithfully, by keeping the subject whole and closed up. Here, it is the body of the insect, not the microscope, which is the window, thus allowing Hooke some (limited) access to a more genuine sense of interiority. It is particularly interesting that Hooke's imagery here is the reverse of that used by Ford; in Hooke's description, opening doors is not intimate

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[30] Fournier, pp. 31–32.

[31] See also Fournier, p. 33, on Jan Swammerdam's anxieties in this regard.

but destructive and reduces accurate visibility, whereas looking through a window is not distancing but allows one to witness interior functions.

The problem of the fractal nature of surfaces suggests that Hooke's search for visual proof of the inner workings of nature — particularly as attacked by Cavendish, Locke, and by modern critics such as Campbell — was a failure. However, the partial solution based on what can be seen by peeping in at windows suggests this was not the case. This is not just a practical solution of technical method and visibility, but an epistemological one as well. As Mulligan's insightful reading demonstrates, Hooke had a cumulative, incremental approach to knowledge and for him, 'Internality and abstruseness were matters of degree, not of kind.'[32] As I have demonstrated of his epistemological methods, which, rather than enforcing a strict binary between factual certainty and all other levels of probability, allows for contingent knowledge, Hooke does not enforce a binary structure between interior and exterior. The interior, and thus the secret knowledge of the inner workings of nature, is something that can be approached by steps, even while the final step is still elusive.

The incremental approach to knowledge of interiors can also be made with hypothesis, and indeed hypothetical visual images. In Scheme 7, Hooke models a hypothetical atomic structure for crystalline objects (the gravel in urine and 'Cornish diamants' or crystals in flint described in Observations 12 and 13) based on his experiments with the alignment of bullets when arranged into shapes.[33] He theorizes that it is the arrangement of corpuscles (also referred to as the '*texture* of Globules' (p. 86, my emphasis)) that determines the composition of bodies:

> I could make probable, that all these regular figures that are so conspicuously *various* and *curious*, [. . .] arise onely from three or four several positions or postures of *Globular* particles, and those the most plain, obvious, and necessary conjunctions of such figur'd particles that are possible, so that supposing such and such plain and obvious causes

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[32] Mulligan, 'Robert Hooke and Certain Knowledge', p. 156. Mulligan's choice of words here suggestively allude to Milton, echoing Raphael's words to Adam on angelic and human reason: 'Differing but in degree, of kind the same.' John Milton, *Paradise Lost*, ed. by Alastair Fowler, 2nd edn (Harlow: Longman, 1998), V. 490.

[33] The description in Observation 12 refers to 'the second *Figure* of the sixth *Plate*' (p. 81), but this is clearly an error and the description in fact corresponds to Scheme 7, Fig. 2.

> concurring the *coagulating particles* must necessarily compose a body of such a determinate regular figure, and no other. (p. 85)

This hypothesis cannot be confirmed by the microscope, but is, as a stage of thought, a valuable contribution to the incremental development of knowledge. Hooke outlines the reasons for his hypothesis and the method he would follow to test it, which substantiates the idea that the hypothesis is a step in the incremental development of knowledge. The nature of Hooke's hypothesis also demonstrates how he believes observation at a micro level can lead to understanding and knowledge: because there is some degree of causality in the arrangement of particles.

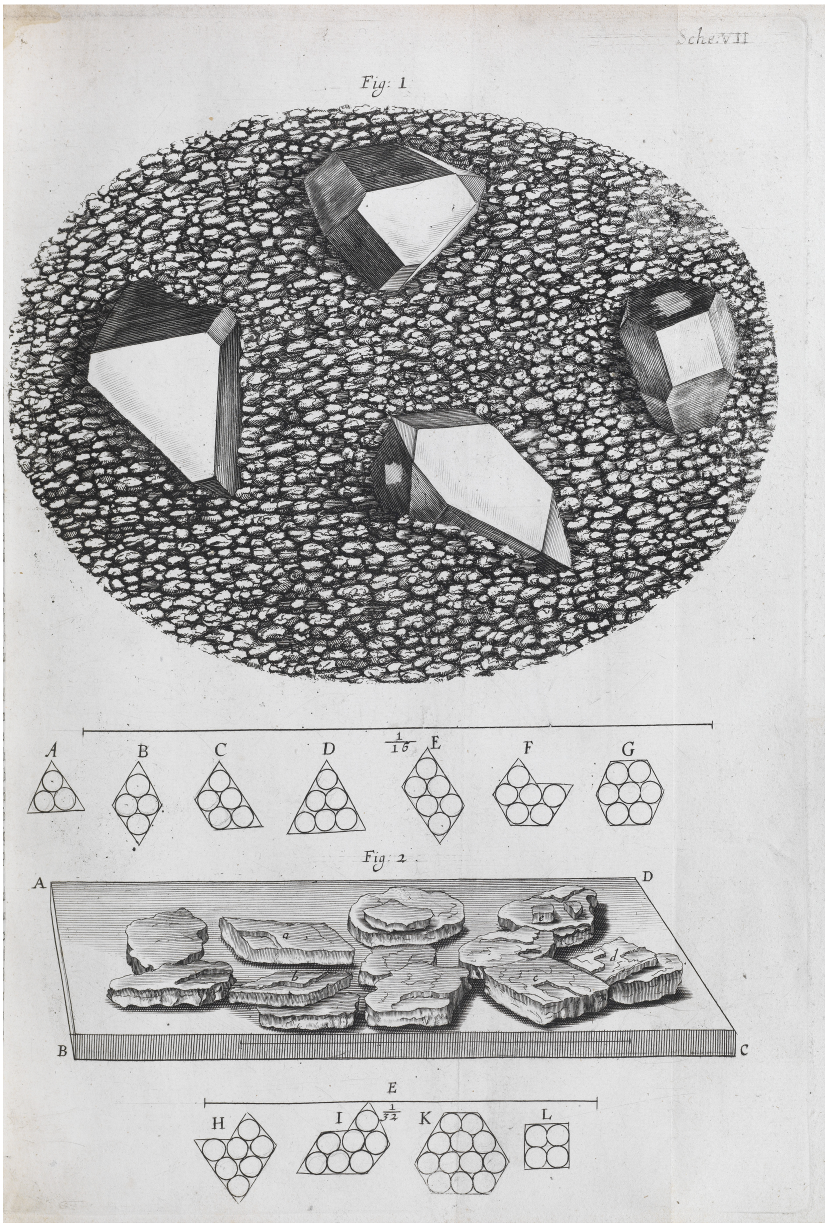

Fig. 1.4. Robert Hooke, *Micrographia* (London, 1665), Scheme 7. Photo: RS.9433 © The Royal Society.

Hooke outlines some of the philosophical advantages of his theory, should it prove true:

> And fourthly, for the usefulness of this knowledge, when acquir'd, certainly none can doubt, that considers that it caries us a step forward into the Labirinth of Nature, in the right way towards the end we propose our selves in all Phillosophical Enquiries. So that knowing what is the form of Inanimate or Mineral bodies, we shall be the better able to proceed in our next Enquiry after the forms of Vegetative bodies; and last of all, of Animate ones, that seeming to be the highest step of natural knowledge that the mind of man is capable of. (pp. 87–88)

The knowledge of the underlying forms of bodies is a step forward in a wider structure of knowledge and will also lead to greater knowledge of other, more complex, aspects of nature. This even includes the possibility of metaphysical knowledge, and as Henry observes, 'For Hooke it seemed possible to arrive at an understanding of the soul by a gradual progression […] "making the steps or foundations of our Enquiry, Fluidity, Orbiculation, Fixation, Angularization, or Crystallization Germination, or Ebullition, Vegetation, Plantation, Animation, Sensation, Imagination".'[34] The imagery of steps is repeated in Observation 14:

> I judge it [the hypothesis of Observation 13] the second step by which the *Pyramid* of natural knowledge (which is the knowledge of the form of bodies) is to be ascended: And whosover will climb it, must be well furnish'd with that which the Noble *Verulam* [Francis Bacon] calls *Scalam Intellectus*; he must have scaling Ladders, otherwise the steps are so large and high, there will be no getting up them, and consequently little hopes of attaining any higher station. (p. 93)

Hooke refers back to the hypothesis of Observation 13 to again illustrate the stepped or incremental structure he envisions for the attainment of knowledge.

As well as providing evidence for the incremental nature of Hooke's theory of knowledge and an example of the utility of hypothesis, the nature of the hypothesis of

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[34] Henry, p. 154, citing *Micrographia*, p. 127. For reasons of brevity I do not include a discussion of Hooke and spirit or soul here, but for more on this topic see Mulligan, 'Robert Hooke and Certain Knowledge', esp. pp. 155–54.

Observation 13 is a significant visual and spatial development of corpuscularian ideas. As Ford points out, Hooke was the first person to suggest that the angles of the facets in crystals were related to molecular alignment within the crystal.[35] Norma Emerton shows that Hooke was enlarging on Kepler's structural speculations on snow and mineral crystals, Hooke following Kepler's geometrical tendencies by arranging spherical bullets in geometrical figures. She writes that Hooke believed there was an orderliness and pattern to nature, and that angularization or crystalization was an intermediate stage on the way to organic form.[36] Emerton points out that Hooke (along with Kepler and Huygens) diverged from the majority of those involved in crystal studies in not thinking that the particles themselves had to be polyhedral.[37] Most mechanist microscopists subscribed to the idea that the qualities of bodies were a consequence of the shape of their particles: Leeuwenhoek, when he examined pepper water, expected to find spikey corpuscles abrasive to the tongue to account for its sharp taste.[38] Hooke instead posited spherical particles whose subvisible arrangement, not their shape, was the salient factor in producing crystalline shapes at the macroscopic level.

Hooke's divergence from the focus on the shape of particles to the more abstract notion of the alignment of particles, raises the question of *how* nature yields information visibly, or rather, how man interprets what he observes in nature to produce knowledge; this question is the missing step between the search for interiority and the search for knowledge. The legibility of nature is a recurring theme in microscopy, and brings with

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[35] Ford, *Images of Science*, p. 137.

[36] Norma E. Emerton, *The Scientific Reinterpretation of Form* (Ithaca: Cornell University Press, 1984), pp. 133. Kepler's text is *Strena seu De nive sexangula* (Frankfurt, 1611).

[37] Ibid., pp. 249–50. Emerton puts the success of angular particles down to their expression of a host of chemical and philosophical meanings rooted in the Paracelsian tradition and minimist form theory, including the predominance of the crystalline salt principle and the belief that the form of the part was the same as the form of the whole (p. 250; for the compound as a unified whole in Paracelsian matter theory, see also Ursula Klein and Wolfgang Lefèvre, *Materials in Eighteenth-Century Science: A Historical Ontology* (Cambridge, MA: MIT Press, 2007), p. 41). In a typically eclectic early modern fashion, it is also possible to see echoes of Leucippus, Democritus, and Epicurus (and perhaps even Plato's geometric solids) in the idea of a correspondence between the shapes of atoms and the qualities of the material they made up, although as Cristoph Lüthy points out, the classical atomists left the relation between the shapes of atoms and substances strongly undetermined. 'The Invention of Atomist Iconography', in *The Power of Images in Early Modern Science*, ed. by Lefèvre, Renn, and Schoepflin, pp. 117–38, p. 121.

[38] Jardine, p. 94.

it the intersection of graphic culture and epistemology. As Susan Stewart points out, the '-graphia' element in the title of Hooke's work is significant, in that 'somehow it was the *writing* of the natural, the previously unreadable, which now stood revealed'.[39] Janice Neri comments upon the discrepancy between Hooke's note in the Covel notebook describing 'A Kind of Teek found creeping upon paper', and the corresponding account in *Micrographia*: 'a very small creature creep[ing] over the Book I was reading' (p. 208).[40] Neri suggests that the reworking of this encounter allows Hooke to present himself as scholarly, but it also perhaps suggests a desire to associate his subjects with text and legibility.

The opening observation of *Micrographia*, on the point of a needle, also includes consideration of printed and handwritten points of punctuation: 'the mark of a *full stop* or *period*' (p. 3). This observation, as well as participating in the tradition from geometry of starting with a point, participates in the optical tradition of considering enlarged text through a lens or optical instrument, as undertaken by Seneca, Roger Bacon, and Galileo.[41] It frames the rest of the observations with the idea that reading and interpreting are a part of microscopy.

In Observation 1, as well as noting the imperfections of the graphic point under the microscope, Hooke considers the practice of microscopic writing (both as a curiosity and as a potentially useful technology for secret intelligence). Critics including Elizabeth Spiller and Michael Dennis make a connection between the reading of tiny writing and Hooke's discussion of the writing of the creator in Observation 29 (on the seeds of thyme). Hooke's discussion reads:

> Who knows but *Adam* might from some such contemplation [on what may be learned of the nature, or use, or virtues of bodies, by their several forms and various excellencies and properties], give names to all creatures? If at least his names had any significancy in them of the creature's nature on which he impos'd it; as many (upon what ground I

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[39] Susan Stewart, *On Longing: Narratives of the Miniature, the Gigantic, the Souvenir, the Collection* (Baltimore: Johns Hopkins University Press, 1984), p. 41. As Dennis notes, the term *micrographia* includes the illustrations as well as the words used in the descriptions, literally 'tiny writing or drawing': Dennis, pp. 311, 336.

[40] Janice Neri, *The Insect and the Image: Visualizing Nature in Early Modern Europe, 1500–1700* (Minnesota: University of Minnesota Press, 2011), pp. 129–30.

[41] David Bardell, 'The Invention of the Microscope', *Bios*, 75 (2004), 78–84 (pp. 78, 79, 81).

> know not) have suppos'd: And who knows, but the Creator may, in those characters, have written and engraven many of his most mysterious designs and counsels, and given man a capacity, which, assisted with diligence and industry, may be able to read and understand them. (p. 154)

The passage makes reference to the pre-lapsarian language of Adam and wonders whether this language was 'written and engraven' by the creator in his creature's 'characters' (i.e. the forms, excellencies, and properties which reveal their nature), and whether this could possibly be read and understood by man — the implication being that if so, this would be achievable by the scrutiny of nature.[42] Spiller makes the connection between this passage and the microscopical observation of letters and texts, but she oversimplifies the relation.[43] In quoting from the passage above, she ignores the context (given here in square brackets and quoted from Hooke's previous sentence) of what 'such contemplation' refers to beyond the generality of the microscopical observation of nature. She also omits by ellipsis the phrases in which Hooke questions whether or not Adam's ability to rightly name the creatures was associated with any particular significance in the names themselves. In full, the quotation reveals an altogether more complex set of ideas. Spiller's simple association of the writing and engraving of nature by the creator with microscopical text suggests a direct ability to read the book of nature, where the causes and inner workings of phenomena are knowable by their visible form. Similarly Dennis, in his reading of this passage, sees in the connection between the concept of *micrographia* and Adam's naming, the idea that the microscope (when used with diligence and industry) has the power to restore man's sight and ability to read God's non-alphabetic writing in an act of re-presenting: 'Adam simply saw and knew; man would do the same, as his microscopes and telescopes improved and he understood more about the (re)production of form.'[44] However, Hooke, with his interjection about the significance of names, queries the legitimacy of this position of direct interpretation.

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[42] Adam's naming of the animals in Genesis 2. 19 led to a popular belief that Adam spoke in a language with perfect congruence between sign and referent. The loss of this language was used as evidence of the corruption of man's faculties at the fall, and the interest in language systems by Royal Society members (including Hooke who used both John Wilkins's and Francis Lodwick's artificial languages) was related to the hope that (as Hooke discusses in his preface) these faculties could be redeemed.

[43] Spiller, pp. 137–39.

[44] Dennis, p. 336.

Svetlana Alpers offers a rather more subtle reading which observes this tension, concluding that, while Hooke turns away from the authority of texts to nature herself, he still wants nature to be not only visible but readable.[45] In the passage from Hooke it is the contemplation of the forms and properties of nature that is important to Adam's ability to name, not the particular significance of the naming word itself. This is evocative of the scientific act of classification based on physical observation rather than a mystical linguistic trick. Similarly when Hooke suggests that man might have the capacity to read the divine inscription of nature, he uses the phrase 'read and understand', again suggesting a level of consideration, thought, and interpretation beyond the act of simply seeing and knowing. As with his hypothetical atomic structure of crystals, Hooke seems to lean towards a theory of nature as legible, in that it is understandable from its visual cues, but also requiring of interpretation.

Another significant aspect of Hooke's treatment of the theme of -*graphia*, is that while the consideration of the full stop in Observation 1 is suggestive of the analogy between reading text and interpreting nature, Hooke also uses it to highlight a disanalogy: the imperfection of man-made text as revealed by the microscope compared to the perfection of magnified nature. The period viewed under the microscope is described as '*disfigur'd*', '*deformed*', and '*rugged*', and looking at the illustration in Scheme 2 (see Fig. 1.5), we can agree with Hooke that regardless of how even and black a period looks with the naked eye, under the microscope it looks 'like a great splatch of *London* dirt' (p. 3). This suggests some ambivalence about using the reading of text as a direct model for interpreting nature, at the same time as letting a wider, more metaphorical analogy hold. This also extends to other man-made objects and in his discussion of the enlarged needle point (also illustrated in Scheme 2) shown to be pitted and rough, Hooke writes of the revelation of the 'rudeness and bungling of *Art* [...] whereas in the works of *Nature*, the deepest Discoveries shew us the greatest Excellencies' (p. 2). Ambiguity and the need for interpretation in the reading of tiny writing is also suggested by the brief description of the letter O as viewed under a microscope (p. 4). The O is considered for the suggestiveness of its shape and Hooke compares the roundness (or rather lack thereof) of a drawn circle with that of the point, thus bringing the letter, which can symbolize (among numerous other things) 'the

[45] Svetlana Alpers, *The Art of Describing: Dutch Art in the Seventeenth Century* (Chicago: University of Chicago Press, 1983), p. 93.

world', into the chain of analogies already made between the magnified point and 'those vaster bodies (which comparatively are called also Points) such as the *Earth*, *Sun*, or *Planets*' (p. 2).

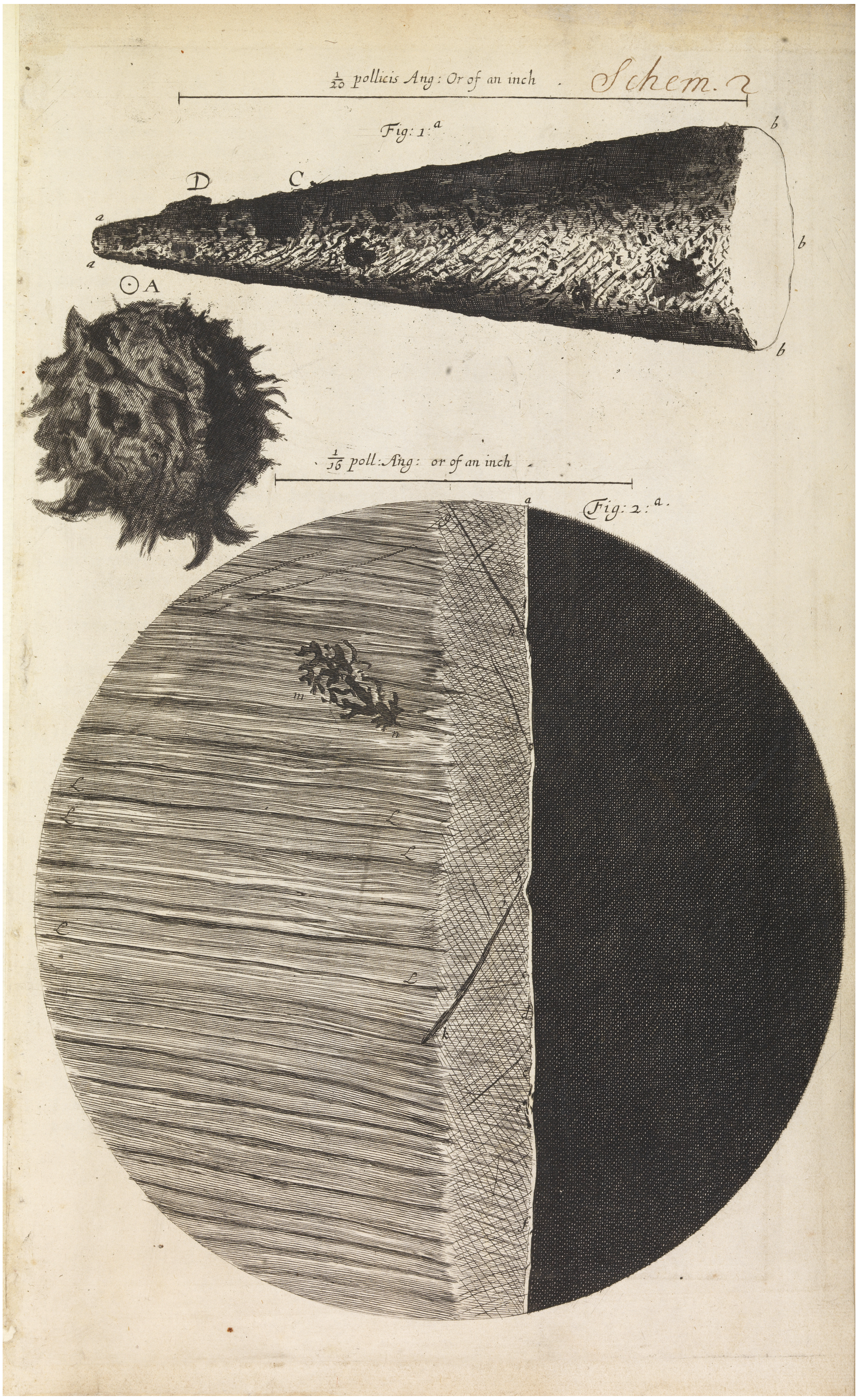

Fig. 1.5. Robert Hooke, *Micrographia* (London, 1665), Scheme 2. Photo: RS.8429 © The Royal Society.

As Catherine Wilson observes, except in a few lucky instances where structure and function seemed to explain one another, microscopists were faced with 'the absolute unintelligibility of the structures perceived: their scientific muteness'. Microscopy could reveal muscle fibres or vessels for sap, but 'it did not really show how much of anything could happen'.[46] This does not support the microscopist as amanuensis model suggested by Dennis, but rather one that requires the microscopist to interpret what he sees. In Observation 1, Hooke makes an analogy between learning to write and draw and the method of making observations in natural history. He likens the way we must learn our letters and draw single strokes before writing whole sentences or drawing larger pictures to the way we must, in physical enquiries,

> endeavour to follow Nature in the more *plain* and *easie* ways she treads in the most *simple* and *uncompounded bodies*, to trace her steps, and be acquainted with her manner of walking there, before we venture our selves into the multitude of *meanders* she has in *bodies of a more complicated* nature; lest, being unable to distinguish and judge of our way, we quickly lose both *Nature* our Guide, and *our selves* too, and are left to wander in the *labyrinth* of groundless opinions; wanting both *judgment*, that *light*, and *experience*, that *clew*, which should direct our proceedings. (p. 1)

While this passage alludes to the metaphor of reading the book of nature by analogy with human writing and drawing, I think it suggests a far less immediate level of comprehension than is suggested by Dennis and Spiller, and indeed connects it with the idea of incremental knowledge. It also emphasizes the agency of the practitioner by its incorporation of writing and drawing into the metaphor of the book of nature, more usually associated with only the passive act of reading. Hooke's conception of knowledge relies much more on experience and judgement, and acknowledges the difficulty and contingency of reading nature, of the 'scientific muteness' of the object seen through the lens. We do not simply see and know as Dennis claims; we need the light of judgement and the clue of experience to guide us.

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[46] Catherine Wilson, *The Invisible World: Early Modern Philosophy and the Invention of the Microscope* (Princeton: Princeton University Press, 1995), p. 230.

Micro and Macro Worlds

Hooke's use in the preface of the New World metaphor to refer to the microscopical world suggests an epistemological continuity between the macro and micro worlds. Indeed this assumption of consistency is central to the doctrines of mechanical philosophy and, as Fournier notes, 'Hooke insisted that for any effect whose cause is invisible it is necessary to make an analogy with a similar effect whose cause is visible.'[47] Zwierlein writes of the New World metaphor that it 'embodies the claim that the regions beyond the threshold of visibility are as accessible (and exploitable) as, earlier, it had been claimed of America'.[48] However, Zwierlein's thought provoking essay goes on to highlight the ambivalent relationship between the visible and subvisible worlds, citing figures such as Locke and Cavendish to question the corpuscularian assumption that there is a link of cause and effect between the two worlds, and describing the never-ending dialectic between wonder and assimilation at the heart of early modern microscopy.[49] In this section, I examine the relationship between the two worlds, in particular the ways in which reference to the macro world is used to explore the new and unknown micro world. I suggest that while the relationship includes ideas of correspondence, this is not a narrative of assimilation of the micro to the macro, and that Hooke also leaves room for discontinuities and the exploration of the micro world on its own terms.

While I admire Zwierlein's sensitive teasing out of these epistemological complexities, I believe her positioning of Hooke in relation to this context assumes a more positivist epistemology for him than his work in fact suggests. Zwierlein cites Hooke's comments in the preface about the 'invisible Notions' and 'fine dreams' of natural philosophers before Bacon, and then questions whether the porousness of the boundary between smallness and nothingness in seventeenth-century microscopic texts means that, 'the separation of subvisible fact from invisible fiction is more difficult than Hooke contends'.[50] However, for Hooke, there is a distinct difference between the pre-Baconian notions and dreams, which are not based on empirical evidence, and the best guesses or hypotheses of mechanical philosophy, which are. As I have demonstrated,

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[47] Fournier, p. 52.

[48] Zwierlein, p. 71.

[49] Zwierlein, pp. 73, 77.

[50] Zwierlein, p. 70.

meaningful visibility in the subvisible realm is not as simple as the binary notion of fact; it is contingent and interpretive and exists in a space of hypothesis, somewhere between fact and fiction. And, as with Hooke's epistemology more generally, while he strives towards the determination of fact, knowledge also exists in the realm of what is most probable based on current data, again, a realm which lies somewhere between fact and fiction. Zwierlein compares Hooke's belief that 'the epistemological "gap" between the worlds above and below the threshold of sight can be filled', and that the '"*Schematism* and *Texture*"' of objects will provide clues to the '"true reason of all their *Phaemomena*"', to Catherine Wilson's observation of the '"scientific muteness"' of the structures perceived with the microscope. Zwierlein deems this to imply failure on Hooke's part: 'Hooke rarely succeeds in meaningfully correlating form and function'.[51] However, Hooke's incremental approach to knowledge makes a binary between success and failure an inappropriate model; partial successes, hypotheses, even failures, all point the way for future experiments, future scientists, and future technology. Also, the layer of interpretation required to understand the significance of microscopic structures (rather than some sort of Adamic instant comprehension) suggests that for Hooke the 'scientific muteness' of microscopical images is not an inherent epistemological gap, but rather an initial stage of unfamiliarity to be overcome with judgement and experience.

Finally Zwierlein suggests that the presence of both assimilation and wonder in *Micrographia* represents the unsuccessfulness of Hooke's attempt to assimilate and make familiar the objects of his study. She writes, 'on the one hand, Hooke assimilates the new strangeness: on the other, to guard their specificity, he has to insist on the otherness of the discoveries', and 'By juxtaposing the old wonder to the new, Hooke attempts to categorize his microscopic animals, and to render them less "strange" — not wholly successfully'.[52] In a similar vein to Zwierlein, Ford notes that Hooke was 'concerned with making familiar objects appear larger' — insects, seeds, textiles — and that it was other microscopists, such as Leeuwenhoek, who really revolutionized the science with the discoveries of protozoa and other micro-organisms.[53] Likewise, Margaret 'Espinasse writes of the 'power of assimilation' in Hooke's comparisons

[51] Zwierlein, p. 72.

[52] Zwierlein, pp. 76, 77. The quotation from p. 77 refers to *Micrographia*, pp. 186–87.

[53] Ford, *Images of Science*, p. 30.

(where the gnat is like an opossum and spider legs are like levers), and Alpers observes that the illustration of seeds of thyme in Scheme 18 looks just like a dish of lemons as would be painted in the Dutch tradition.[54] But while this aspect of familiarity is certainly present in Hooke, these critics miss what is unfamiliar in the *Micrographia.* Howard Gest, for example, attributes to Hooke the first accurate description and depiction of any microorganism.[55] Figure 1 of Scheme 12 shows a magnified view of what to the naked eye appears as 'a small white spot of hairy mould' (p. 125) and which the graphical scale shows to represent just 1/32 of an inch (see Fig. 1.9). Hooke studies both the familiar and the unfamiliar, and furthermore he finds the unfamiliar in the familiar, and indeed the familiar in the unfamiliar. As I show in this section, Hooke does not treat wonder and assimilation as an either/or; for Hooke they are not expressions of comprehension at which to fail or succeed, but rather, techniques of exploration which can be used simultaneously and interconnectedly. I show that Hooke's approach is much more in line with Zwierlein's own idea of the 'dialectic between wonder and assimilation [as] a never-ending process'.[56]

Zwierlein's reading of Hooke suggests that he believed in the continuity and correspondence between the macro and micro, or visible and subvisible, worlds. With the idea of incremental knowledge, and the importance of the judgement and experience of the microscopist in interpreting what he or she sees through the microscope, a relationship between the existing knowledge of the microscopist and the new knowledge discovered with the instrument is implied. Similarly with the idea of an underlying structure of universal particles, some sort of material relationship between the micro and macro worlds is understood. However, these relationships are not strictly defined and in this section I show that they are more complicated than simple continuity or correspondence. Like Hooke's hypothesis that it is the alignment rather than the shape of particles that determines their nature, the relationship between the macro and micro worlds — and indeed how practitioners come to know the micro world — relies in part on disruptions to continuity.

One source of anxiety about the micro world comes from the uncertainty of the image in the lens. If a practitioner uses a telescope to view an object at a distance, he or

[54] Margaret 'Espinasse, *Robert Hooke* (London: William Heineman, 1956), p. 57; Alpers, p. 84.

[55] Howard Gest, 'The Remarkable Vision of Robert Hooke (1635–1703): First Observer of the Microbial World', *Perspectives in Biology and Medicine*, 48 (2005), 266–72 (p. 267).

[56] Zwierlein, p. 77.

she can compare the image seen via the instrument with a close up view of the object, and thus verify both the optical effect and the image. Indeed, Galileo's experiments of reading distant text through a telescope (experiments which Hooke persuaded the Royal Society to reproduce) were done to demonstrate the veracity of the instrument. With the microscope no such check with the naked eye is possible. However, Hooke does create something similar to this verification effect in Observation 1 with his examination of minute text. Although the minute text itself cannot be checked with the naked eye, the reader can verify the enlarged image against his or her knowledge of the text.[57] Although Hooke acknowledges the difficulty of resolving images in lenses, he always expresses confidence in the microscope, treating the image in the lens as faithful and rather watching and guarding against human errors of interpretation. The results of Observation 1 emphasize this. The flaws revealed in the magnified full stop or the point of the needle (see Fig. 1.5) do not cause Hooke or the reader to question the accuracy of the microscope, they cause us to question unassisted human perceptions at the macro level. Hooke considers the point of a needle, which is, 'for the most part, made so sharp, that the naked eye cannot distinguish any parts of it' (p. 1). However, viewed with a good microscope, 'we may find that the *top* of a Needle (though as to the sense very *sharp*) appears a *broad*, *blunt*, and very *irregular* end; not resembling a cone, as is imagin'd, but onely a piece of a tapering body' (pp. 1–2). Rather than assimilating what is seen in the lens to existing knowledge, Hooke allows this new knowledge of the micro world to destabilize the certainty of the macro world. What had once been known by sense, and indeed had become axiomatic knowledge — as Hooke highlights by commenting on the superlative idiom 'As sharp as a Needle' (p. 2) — has now become only 'imagin'd' knowledge. As part of the first observation, this destabilization of existing knowledge frames the rest of the book.

Although the idea of destabilizing existing knowledge might seem anxiety inducing, it speaks of honesty and helps the reader to trust in something unverifiable. In

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[57] This is similar to what Ian Hacking refers to as 'the argument of the grid', which describes the modern practice of producing minuscule grids by drawing a grid of a known size and with identifying markers and reducing it photographically. When the tiny grid is viewed through the microscope and the viewer sees the same identifying markers as in the original, it becomes impossible to doubt the verity of the image. See Ian Hacking, 'Do we See through a Microscope?', in *Images of Science: essays on realism and Empiricism with a Reply from Bas C. Van Fraasen*, ed. by Paul M. Churchland and Clifford A. Hooker (Chicago: University of Chicago Press, 1985), pp. 132–52 (p. 146).

a similar way, Hooke's recording of failed experiments or disproven hypotheses actually helps to generate trust, both in the instrument and the practitioner.[58] In considering a seemingly plausible hypothesis for the porous texture of sponge, Hooke writes:

> Nor from this *Hypothesis* would it have been difficult to explicate, how […]: But this inded [*sic*] was but a conjecture; and upon a more accurate enquiry into the form of it with the *Microscope*, it seems not to be the true origine of them. (p. 137)

Hooke emphasizes the role of the microscope as a verifier of data and demonstrates himself to be an honest reporter and to be enacting the watchfulness over error he recommends in the preface. In Observation 32, Hooke examines a hypothesis about the structure of human hair based on an analogy with the hairs of other creatures. The hypothesis is debunked by evidence from the microscope: 'though I grant that by an *Analogie* one may suppose them so, […] I think we have not the least encouragement […] from the *Microscope*, much less positively to assert them such' (pp. 157–58). This becomes a general principle:

> And therefore I think it no way agreeable to a true natural Historian, to pretend to be so sharp-sighted, as to see what a pre-conceiv'd *Hypothesis* tells them should be there, where another man, though perhaps as seeing, but not forestall'd, can discover no such matter. (p. 158)

Again, the microscope is used to verify or falsify hypothesis, and Hooke is watchful for the human error of preconception, which has the potential to affect what a man sees. The reading of Hooke that sees a presumption of continuity between the micro and macro worlds is largely based on Hooke's use of analogy. However, we see here that analogy is admitted as a means of structuring the exploration of the natural world by suggesting hypotheses to be tested, but it does not itself presume the status of fact, nor is it to be slavishly followed.

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[58] On the use of a rhetoric of truthfulness to help instil confidence in experimental accounts, see Steven Shapin, 'Pump and Circumstance: Robert Boyle's Literary Technology', *Social Studies of Science*, 14 (1984), 481–520 (pp. 493–94).

Hooke makes frequent use of analogy between the micro and macro world as a tool for negotiating the threshold of the subvisible world. This is used in several key ways: to explain an observation to the reader; to deduce the hypothetical cause of phenomena (in conjectures with varying degrees of certainty) and offer rational support to the likelihood of this theory; and to explore phenomena as a precursor to making deductions about it. A lot of these analogies rely on Hooke's genius as a mechanic and inventor; as Jim Bennett claims, Hooke's knowledge of mechanics, of instruments and machines in the macro world, 'tuned and prepared the mind to construct explanations of the unseen, micro world that lay behind all the phenomena of our experience'.[59] Bennett cites Hooke's 'General Scheme' where Hooke asserts that mathematics and mechanics help the mind in its thinking about experiments: mathematics provides a model for reasoning and mechanics demonstrates general laws of motion and physical operations.[60] Even where natural analogies are used, they are understood in a mechanical way that relies on general laws and universal properties. That much continuity is assumed. However, the allusion to this method in the preface also highlights its contingency: 'because we may perhaps be inabled to discern all the secret workings of Nature, *almost* in the same manner as we do those that are the productions of Art' (sig. a2^{v}, my emphasis).

There are numerous examples of Hooke's various uses of analogy with the macro world. In Observation 21, on moss, Hooke's macro analogy has a purely explanatory intent: 'To explain my meaning a little better by a gross Similitude: Suppose a curious piece of Clock-work [...]' (p. 133). In Observation 38, on the wings of flies, Hooke uses the macro analogy of the vibration of musical strings to deduce the swiftness of wing beats:

> And these vibrations or motions to and fro [of the wings of flies] between the two limits seem so swift, that 'tis very probable (from the sound it affords, if it be compar'd with the vibration of a musical string, tun'd unison to it) it makes many hundreds, if not some thousands of vibrations in a second minute of time. And, if we may be allow'd to ghess by the sound, the wing of a Bee is yet more swift, for the tone is much more acute. (p. 173)

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[59] Jim Bennett, 'Instruments and Ingenuity', in *Robert Hooke: Tercentennial Studies*, ed. by Cooper and Hunter, pp. 65–76 (p. 67).

[60] Ibid.; see *Posthumous Works*, pp. 19–20.

Hooke uses the analogy of the musical string to deduce a persuasively rational hypothesis about a phenomenon unavailable to the unassisted human senses.

In several instances, analogy between the micro and macro worlds is used for multiple ends. In his account of the physiology of stinging nettles Hooke uses mechanical analogies to describe and explain the phenomena in his verbal description: ‘the whole surface of it very thick set with turn-Pikes, or sharp Needles’ (p. 142), and ‘those small Bodkins were but the Syringe-pipes, or Glyster-pipes, which first made way into the skin, and then served to convey that poisonous juice’ (p. 143). As well as helping describe and explain the phenomenon to the reader, the language also suggests the likelihood that Hooke’s familiarity with artificial devices, such as syringes and glass pipes, helped him to understand what he was seeing in the first place. The use of metaphors rather than similes possibly indicate a closer relationship between the vehicle and referent in Hooke’s thought in these instances. Similarly, in his account of bee stings, there is a mix of similetic analogies which suggest description to aid the reader in picturing the phenomenon — ‘a sheath, […] shap’d almost like a Holster of a Pistol’ (p. 163), with barbed protuberences ‘which seem’d like so many Thorns growing on a briar, or rather like so many Cat’s Claws’ (ibid.) — and metaphoric ones, ‘this syringe-pipe’ (p. 164) which are likely also a part of Hooke’s deductive reasoning about the function of the parts.

Hooke’s analogies are, for the most part, stable ways of developing an understanding of the unknown in relation to what is already familiar. However there are also ways in which he uses analogy to explore the realm of uncertainty. When considering a moth, Hooke uses an analogy with bird feathers to describe the texture of tiny scales on the body and parts of the wings. However, he then writes:

> Whether the tufts of any or all of these small Feathers, consisted of such component particles as the Feathers of Birds, I much doubt, because I find that nature does not alwaies keep, or operate after the same method, in smaller and bigger creatures. (p. 196)

Hooke’s recounting of his finding that nature isn’t always consistent in her methods between small and large creatures destabilizes the continuity between the micro and macro worlds which the analogy between bird feathers and the texture of moth wings seems to rely on. Hooke thus draws attention to the much more metaphorical use of the analogy as a tool for exploring relationships rather than categorizing according to known principles. Immediately after admitting this doubt about the degree of likeness between bird feathers and moth wings, Hooke continues with his feather analogy, and then adds other analogies or comparisons, producing a network of ideas and images which include the membranous wings of dragon flies, the short bristles of flesh flies, the placement of tiles on a house, the lively colouring of butterflies, and the backbone of a herring (p. 197). This use of analogy seems to be more about creating a network of related thoughts which might act as stimulus for the reader and which record the mental process of the practitioner, rather than attempting to assimilate the microscopic image to a known pattern.

Another deviation from the assimilative uses of analogy comes from the fact that as well as developing an understanding of the micro world by reference to the macro, Hooke also uses internal analogies, that is, references to other parts of the micro world. These references appear to be of limited utility to the reader; unless he or she were one of the few other contemporary microscopists, the reader would have no first-hand experience of these supposed referents. The knowledge requisite for this sort of analogy comes either from reading other microscopical texts, from reading other sections of the *Micrographia*, or from the reader's imagination. In Observation 23, on sea-weed, Hooke writes:

> I found, that each of the Branches or Figures of it, did, by the range of its pores, exhibit just such a texture, the rows of pores crossing one another, much after the manner as the rows of eyes do which are describ'd in the *26. Scheme.* (pp. 140–41)

The eyes in Scheme 26 are those of the blue fly described in Observation 42. This is not only an analogy to an object of the micro world, it is one that the reader has yet to encounter in the book (presuming the observations are being read in their published order).[61] This technique of referencing the unfamiliar reveals that Hooke's analogies

[61] The order in which the observations appear in *Micrographia* is not representative of the order in which Hooke made his observations or presented them to the Royal Society, however the observation of seaweed was made two months before the observation of the drone fly so chronology of observation does not account for the inclusion of the comparison to the fly. For a table showing 'Chronology of Hooke's

and comparisons are not always illustrative or operating wholly in an explanatory way. These moments feels more exploratory with Hooke making comparisons between his microscopical observations as if he were drawing up a map of relations between objects (even only partially understood objects) in this new world. For the reader this is a revelation of Hooke's process of understanding and a record of his mental associations. It also has the effect of helping the reader take a step up the ladder of understanding by letting go of the reliance on macro references; the reader is being trained in scientific encounters with the unknown. Hooke steps further into the microscopical world, and we go with him.

In another method whereby Hooke eschews reference to the macro world, Hooke — as well as the positing of his own hypothetical underlying structure for crystals in Observations 12 and 13 discussed above — notes that the pores of Kettering stone 'minded me of the pores which *DesCartes* allow[s] his *materia subtilis* between the *aethereal* globules' (p. 94), and compares the size of the pores in cork to 'the *Atoms* which *Epicurus* fancy'd' (p. 114). As well as internal micro-world comparisons, Hooke goes a step further and makes connections between his microscopical observations and theoretical subvisible imagery. This reiterates the inclusivity of his epistemology, which allows theories and hypotheses to be a sort of knowledge, and also traces the associations of ideas, which may in turn lead to new theories.

In the same way that the microscope forced a re-evaluation of the understanding of macro objects such as the needle, and the relational context of qualities such as sharpness, Hooke's use of analogy does not only work in one direction. He does not simply use the familiar to understand the unfamiliar, but also forges explanatory relationships between different unfamiliar objects, and between unfamiliar objects and hypothetical ideas. The questioning of direct correspondence between micro and macro in the observation on moths allows analogy to be used in a less rigid, more exploratory and metaphorical way. As such it becomes a tool for developing thought and understanding rather than just a tool for categorizing new discoveries according to existing principles.

Observations', see John T. Harwood, 'Rhetoric and Graphics in *Micrographia*', in *Robert Hooke: New Studies*, ed. by Hunter and Schaffer, pp. 119–47 (pp. 124–25, Table 1).

Fig. 1.6. Robert Hooke, *Micrographia* (London, 1665), Scheme 26. Photo: RS.9445 © The Royal Society.

To understand this further we must consider Hooke's portrayal and experience of the scale relationship between micro and macro objects. As Fournier notes, there was no agreed method amongst the new scientists to indicate the actual size of microscopical objects in illustrations, which hampered the growth of a coherent body of knowledge.[62] Jardine also notes that practitioners experienced and remarked on the loss of a sense of scale in making observations with the microscope.[63] Hooke's own methods of portraying scale are inconsistent. While he does attempt accurate and numerical measurements of scale in his verbal descriptions, of the thirty-eight illustrated plates in *Micrographia* only eight bear a graphical scale, and more than half have several figures of different scales on the same plate with no means of visual distinction. Even in those schemes with graphical scales it is not always clear to which figures they refer. In Scheme 26, an illustration of a blue fly (Figure 1) overlaps an illustration of its wing at a larger magnification (Figure 2) in such a way as to suggest that the two objects are interacting, that the fly is perched on its own enlarged wing (see Fig. 1.6). Although Hooke's manuscript sketches of microscopically observed insects in the Covel notebook contain scale references — drawings or marks alongside the magnified image to indicate the 'real bignesse' — and although this was a known method used in published works by other microscopists such as Stelluti, Hooke includes this sort of scale reference in just one of his published engravings (Scheme 21).[64] This is particularly provoking in its potential pun on the word *scale*: the plate contains three illustrations of fish scales all drawn to different scales of size, which are not indicated by the image in any way (see Fig. 1.7).

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[62] Fournier, p. 38.

[63] Jardine, p. 107. It was not just the microscope that distorted the sense of scale; Jardine also describes the misleading effects of the camera obscura.

[64] For a detailed examination of Hooke's work in the Covel manuscript and demonstration that this was preparatory work for the *Micrographia*, see Neri, pp. 123–38, particularly p. 127 where she describes the references to actual size. For an example of the inclusion of an actual size reference in a published work, Stelluti's *Persio Tradotto* includes an engraving of a curculio beetle seen through a microscope, alongside the beetle at its real, unmagnified size, and an anatomical detail, reproduced in Hellmut Lehmann-Haupt, 'The Microscope and the Book', in *Festschrift für Claus Nissen*, ed. by Guido Pressler and Elisabeth Geck (Wiesbaden: Guido Pressler Verlag, 1973), pp. 471–502 (p. 480).

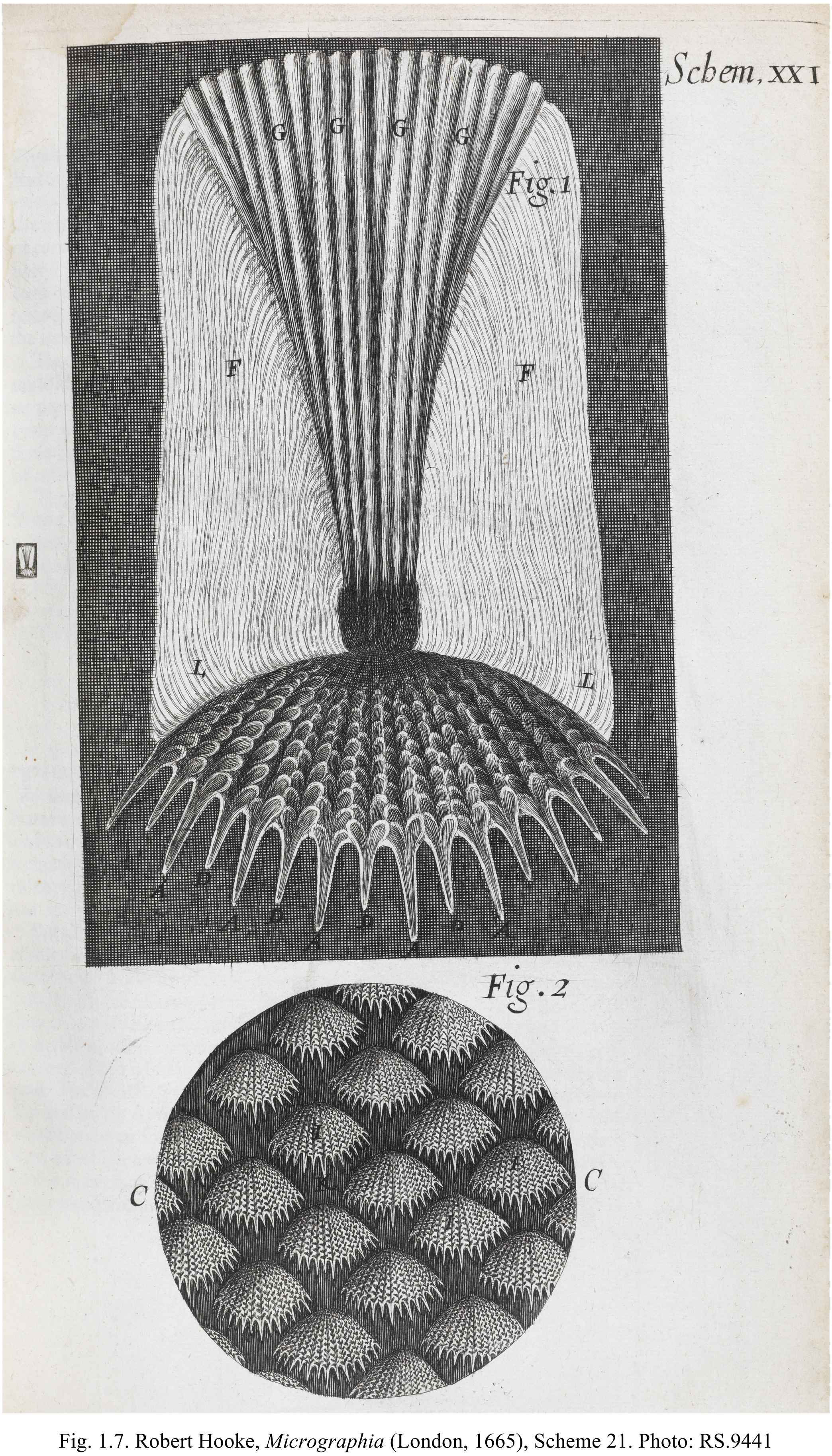

Fig. 1.7. Robert Hooke, *Micrographia* (London, 1665), Scheme 21. Photo: RS.9441

Neri claims of *Micrographia* that 'Not only did the title of the book clearly state the subject matter and the text include detailed descriptions of the microscope, but the illustrations themselves almost always announced their status as magnified images', highlighting the illustrations presented in a round frame or as large format foldouts to support her claim.[65] However, just thirteen of the thirty-eight schemes include images in round frames (and most of these schemes also contain unframed figures) and only ten schemes require folding plates, less than a third in each case and certainly a stretch for Neri's 'often'. Considering the lack of scale referencing in the images themselves (i.e. without the support of the textual description), and indeed the confusion of having different scales within the same plate, I argue that these microscopic objects are presented much more ambiguously. Even the scale references included in the textual descriptions are not without ambiguity. While I think Hooke makes a genuine effort to record this data as accurately as he can (microscopical measurement was still highly imperfect), the dizzying mental effect of reading Hooke's calculation that 1 inch of cork contains 1,259,712,000 cells is undeniable and I think there is a certain amount of what we would now call 'blinding with science' going on here. Hooke uses this large number to dazzle as well as to inform, his very next phrase, 'a thing almost incredible, did not our *Microscope* assure us of it by ocular demonstration' (p. 114), inspiring wonder and support for the instrument as much as the phenomenon.

The effects of the ambiguity of scale are manifold. In some ways the potential for misreading the illustrations does strengthen the idea of a continuum between micro and macro, which supports the idea behind corpuscularian philosophy of a unified underlying structure. However, as we found with Hooke's use of analogy, the effects are not as simple as interpreting the micro in terms of the macro. The ambiguity of Hooke's illustrations position the reader to share the microscopist's experience of confronting the unknown in the decontextualized image, before applying the salve of Hooke's explanatory text. This decontextualization heightens our awareness of the relational nature of human knowledge. As Constantijn Huygens wrote in his autobiography on the subject of the dislocation of man as the measure of the universe brought about by new optical technologies such as the microscope and telescope, 'Let

[65] Neri, p. 128.

us in short be aware that it is impossible to call anything 'little' or 'large' except by comparison.'[66]

The use of ambiguity, particularly in the illustrations, allows an event to take place for the reader: a confrontation. Frédérique Aït-Touatì also notes the confusion of scales and the decontextualization in Hooke's pictorial technique, and describes Scheme 24 — the image of the head of a drone fly which both Aït-Touatì and Harwood observe to be the size of a human head — as a 'frightening encounter' which occurs 'face to face' (see Fig. 1.2).[67] These encounters create moments of potential unity but also uncertainty between the two worlds, and foster an awareness of the roles of the relative and referential in building new knowledge. These effects of encounter all help the reader to get a sense of actually entering into the microscopic world. Bachelard, in considering the miniature, writes that 'the process of imagination [...] poses a problem that must be distinguished from the general problem of geometrical similarities' (i.e. that a geometrician sees the same thing in two similar figures drawn to different scales).[68] In exploring this problem of imagining the miniature he considers the possibility that 'in order to enter into the domain where we imagine, we are forced to cross the threshold of absurdity', and describes a fairy tale in which, like the fly perched on its own wing (see Fig. 1.6), a hero gets into a coach the size of a bean whilst carrying a large bag of beans on his shoulder.[69] Bachelard concludes that 'one must go beyond logic in order to experience what is large in what is small'.[70] I think the ambiguity of scale and absence of context in Hooke's images allows the reader to access something of this nature, to go beyond logic and cross the threshold of ambiguity, for example in his or her face to face encounter with a human sized fly.

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[66] J. P. Worp, 'Fragment einer Autobiographie', *Bijdragen en Mededelingen van het Historisch Genootschap*, 18 (1897), 1–122 (p. 120), quoted and translated in Alpers, p. 18. The Latin reads, '*Tandem hoc sciatur, nihil usquam parvi aut magni extare nisi ex parallelo*'. Huygens's autobiography was started in 1629, he died in 1687.

[67] Frédérique Aït-Touatì, *Fictions of the Cosmos: Science and Literature in the Seventeenth Century*, trans. by Susan Emanuel (Chicago: University of Chicago Press, 2011), pp. 146, 148; Harwood, p. 144. Although the smaller scale modern facsimile editions are incredibly useful, they do not preserve the spectacular visual impact of the original folio edition. The image of the fly's head measures 28.7 x 25.9 cm.

[68] Bachelard, p. 148.

[69] Bachelard, p. 149.

[70] Bachelard, p. 150.

We also find this idea of encounter, or of going into the micro world, in Hooke's use of verbal microscopy. In Observation 38 on the wings of flies, as well as using a deductive analogy to come up with his hypothesis, he uses a rhetorical microscopy to add support to his hypothesis by helping the reader cross the threshold into the micro world:

> The wing being suppos'd placed in the upmost limit, seems to be put so that the plain of it lies almost *horizontal*, but onely the forepart does dip a little, or is somewhat more deprest; in this position is the wing vibrated or mov'd to the lower limit, being almost arrived at the lower limit, the hinder part of the wing moving somewhat faster then the former, the *Area* of the wing begins to dip behind, and in that posture seems it to be mov'd to the upper limit back again, and thence back again into the first posture, the former part of the *Area* dipping again, as it is moved downwards by means of the quicker motion of the main stem which terminates or edges the forepart of the wing. (pp. 172–73)

There is a microscopic effect in the level of attention paid and in the minuteness of the description of a phenomenon that has been described as 'exceeding swift' (p. 173), which not only makes us imagine the movement as larger and thus visible, but which slows it down sufficiently for us to understand or mentally experience it by enacting a suitable re-proportioning of perception to create not just a visual encounter, but one of experience. This effect is heightened by Hooke pulling back to the macro scale in the next line, 'And these vibrations or motions to and fro between the two limits seem so swift'. As well as reminding us that these motions are swift, the increased pace of the description enacts the wing beats much more succinctly in the reader's mental image of the action. Hooke then goes on to give a numerical estimate of the number of beats per minute to give us a more concrete context for these different mental experiences.

In his digression on perception and proportion in the final of his *Lectures of Light* (a series of lectures read to the Royal Society between February 1680 and May 1682), Hooke contemplates the experience of man in relation to the experience of more minuscule creatures, figuring both in terms of granularity — an idea that he clearly developed from his work on microscopy. Hooke reasons that sensible moments are composites of infinite other discrete moments, comparing the quick movement of a coal of fire at night which appears to the senses as a glowing line, to the slow movement of the same coal which reveals it to be a body being moved through space. Hooke argues that our perception is dependent not only on time but on our size, and compares human perception with the experience of smaller creatures:

> And I do not at all doubt but that the sensible Moments of Creatures are somewhat proportion'd to their Bulk, and that the less a Creature is, the shor[t]er are its sensible Moments; and that a Creature that is a hundred times less than a Man, may distinguish a hundred Moments in the time that a Man distinguishes one. [...] So that many of those Creatures that seem to be very short lived in respect of Man, may yet rationally enough be supposed to have lived, and been sensible of and distinguished as many Moments of time as a Man; because within that space of time it has lived, it has had as many distinct Moments of time, and has had as many distinct Differences of Moments, as a Man hath in the Age he lives.[71]

That this digression is prompted by Hooke's experiments with the microscope is in no doubt. In his next paragraph he writes:

> Now we are sensibly informed by the Microscope, that the least visible Space (which is that which appears under an Angle of half a Minute of a Degree) may be actually distinguished into a thousand sensible Spaces: And could we yet further improve Microscopes, 'tis possible we might distinguish even a thousand more Spaces in every one of those we can now see by the help of those Microscopes we have already. (Ibid.)

The idea of infinite (or at least greater) visual granularity that the microscope offers — the blowing up of space — is integrated into Hooke's notion of experience. And although in this essay Hooke does not try to disrupt the presumed continuity between the macro and micro worlds, he does create a sense of encounter, zooming in and indeed bringing the micro world alive, giving it its own inner consistency by considering the experience and the visual and aural perceptive faculties of those tiny creatures themselves.

Another important aspect of the concept of scale as presented in *Micrographia* is its relationship to the idea of value. In the prefatory material Hooke highlights the metaphorical values of size in a show of false modesty. In his dedicatory epistle to the

[71] *Posthumous Works*, p. 134.

king, he contrasts the '*small* Present' and 'the *meanness* of the *Author*, and of the *Subject*' with 'the *greatness* of your *Mercy* and your *Knowledge*' (sig. A1r). However, Hooke destabalizes this common rhetorical trope at the close of his dedication by suggesting a different assignment of value. He closes:

> Amidst all those *greater* designs [of the Royal Society], I here presume to bring in that which is more *proportionable* to the *smallness* of my abilities, and to offer some of the *least* of all *visible things*, to that *Mighty King,* that has *establisht an Empire* over the best of all *Invisible things* of this World, the *Minds* of Men. (sigs a1v–a2r)

While it holds the outward forms of modesty, this statement also allows Hooke to elevate the value of his offering of 'the *least* of all *visible things*'. Hooke takes advantage of the connection forged between the least of visible things and the invisible by the revelatory function of the microscope (and indeed *Micrographia*), to associate his microscopical offering with 'the best of all *Invisible things*' (emphasized by the use of parallel phrases), 'the *Minds* of Men'. This associates microscopical observation with the whole project of knowledge and learning. In his preface, Hooke also makes an analogy between *Micrographia* and the widow's mite, 'I have at length cast in my mite, into the vast treasury of *A Philosophical History*' (sig. g2v), using the pun on 'mite' (Observation 50 is on mites) to make a serious claim for the value of both his work and his microscopic subjects. As with the question of the sharpness of the needle, and his multifarious uses of macro-, micro-, and theoretical analogies, Hooke's reapportioning of value creates a dialectic of subjective relativity and re-evaluation between the micro and macro worlds.

The Constructed Presentation of Data

In the preface to *Micrographia*, Hooke outlines a method for natural history and philosophy that places a high level of importance not only observation and experiment for producing knowledge, but also on the acts of recording and presenting data. The 'sincere hand' is just as necessary as the 'faithful eye' (sig. a2v), and Hooke praises the inventors of 'Printing, Etching, Graving' (sig. b2r) in the same list as the inventor of

Microscopes, associating methods of transcribing and circulating information with instruments to aid observation, and placing equal weight on both. In Observation 1, discussed above, Hooke compares the process of learning how to make observations in natural history to the process of learning to write or draw: 'We must first endevour to make *letters*, and draw *single* strokes true, before we venture to write whole *Sentences*, or to draw large *Pictures*' (p. 1). Here, recording and transcribing are presented as analogous with observing and experimenting. The spatial concepts of proportion and organization are also recurring themes in Hooke's epistemology. Hooke recommends the 'ranging and registring its [natural history's] Particulars into Philosophical Tables, as may make them most useful for the raising of *Axioms* and *Theories*' (sig. b1^{v}). This outsources the memory to a more reliable and more easily comparable repository, but also organizes the data spatially in a way that actively helps in producing knowledge (axioms and theories). In this section I consider Hooke's principles of transcribing, organizing, and communicating data, and the contribution this makes to knowledge as shown by his illustrations, tables, and other *mise en page* effects. I also show how these principles of spatial organization are related to Hooke's conception of the mental processes of acquiring and developing new knowledge with reference to his ideas about experience and memory.

Hooke was particularly interested in the layout of records and suggests in the preface that it is the arranging of particulars in tables that make them useful to knowledge. Adrian Johns, who suggests the diverse systems of commonplacing still in vogue at the time as a possible inspiration, comments on the importance to Hooke of the visual layout of the book for registering experiments with the Royal Society. Johns writes, 'Only if recorded in a correct manner, pictorially and typographically, could experimental matters of fact help in his project to "rectify the mind".'[72]

In the 'General Scheme', Hooke continues his discussion of the recording of natural history, repeating and expanding on the ideas expressed in the preface to *Micrographia*. He describes:

> a Method of collecting a Philosophical History, which shall be as the Repository of Materials, out of which a new and sound Body of Philosophy may be raised. This is to comprize a brief and plain Account

[72] Adrian Johns, *The Nature of the Book: Print and Knowledge in the Making* (Chicago: University of Chicago Press, 1998), pp. 433, 433n.

> of a great Store of choice and significant Natural and Artificial Operations, Actions and Effects, ranged in a convenient Order, and interwoven here and there with some short Hints of Accidental Remarks or Theories, of corresponding or disagreeing received Opinions, of Doubts and Queries and the like, and indeed until this Repository be pretty well stored with choice and sound Materials, the Work of raising new Axiomes or Theories is not to be attempted, lest beginning without Materials, the whole Design be given over in the middle, for out of this are to be taken the Foundation Stones, on which the whole Structure should be raised, and those ought to be proportioned according to the rest of the Materials.[73]

Much more than the recording of individual pieces of observational data and other information, there is a sense that the value of this data is in considering it as a whole. The data must be 'ranged in a convenient Order', and anything built on it, 'proportioned according to the rest of the Materials'; these are relational tactics which allow natural philosophers to see patterns in the overall enterprise. As Wilding suggests, 'The great advantage of external Memory over internal is that it can employ reason itself, rather than chronology, to order its contents.'[74]

This emphasis on order and proportion is repeated throughout the essay, and is also linked to the use of the senses. In a discussion of assisting the faculties of sense, memory, and understanding (again a development of the preface to *Micrographia*), Hooke writes, 'the Senses are helped by Instruments, Experiments, and comparative Collections, the Memory by writing and entering all things, ranged in the best and most Natural Order.' Hooke continues that the reasons for this are 'to make them material and sensible', to prevent their being lost or forgotten, and to relieve the mind of the drudgery of recalling particulars to memory 'or ranging them in Order, […], or in transposing, jumbling, ranging, methodizing, and the like'.[75] By listing the making of data 'material and sensible' as a reason for this method, and including 'comparative Collections' as an aid to the senses, Hooke confirms that the senses are not just for gathering data but for processing and understanding it visually as well. It is important that data 'are all presented at once to the View: Their Order, Congruity, Disagreement,

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[73] *Posthumous Works*, p. 18.

[74] Wilding, p. 130.

[75] *Posthumous Works*, p. 34.

Similitude, &c. are all manifest to the Eye'.[76] The list of processes of which Hooke seeks to relieve the mind by the physical ordering of data on the page also confirms that spatial arrangement is a part of understanding data, forming new knowledge, and finding the way of proceeding in further scientific enquiry.

Hooke employs various techniques to achieve the visual ordering of information. Johns notes Hooke's use of colour coding in different inks 'to aid immediate perception', and Mulligan comments on the formatting techniques used in Hooke's diary to aid memory and categorization, such as columns for different subjects, underlining, capitalizing, bracketing, colour, and symbols.[77] These techniques are perhaps echoed in the frequent use of italics to highlight key words in the printed text of *Micrographia*.[78]

Hooke also gives instructions about the arranging or ordering of data. On pages 22 to 26 of the 'General Scheme' are lists of various subject headings by which to group data. As well as listing, some of these distributions are also laid out with branching lists and brackets, spatially denoting the relations between classifications. Carl Selkin — writing of the cataloguing style of the poet Thomas Traherne, whose poems and thanksgiving often include bracketed lists — observes that Traherne's catalogues act as 'spatial metaphors for simultaneity'. There is a 'departure from horizontally linear to vertical movement, the actual "stacking" of language', and the reader, as well as accepting that each element in the catalogue can fill the same grammatical slot in a sentence, seems to be led to 'accept them as filling that slot at the same time'.[79] This effect is present in the layout of Hooke's data and contributes to the sense that, although language is linear, this data is presented 'at one view' and somehow exists outside of the temporal experience of reading in an experience that is much more spatial. Hooke also discusses brevity of language and effective use of space on the page so that data is not only clear and unbiased, but is comprised 'in as little room as possible, so as to

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[76] Ibid.

[77] Johns, p. 433; Lotte Mulligan, 'Self-Scrutiny and the Study of Nature: Robert Hooke's Diary as Natural History', *Journal of British Studies*, 35 (1996), 311–42 (pp. 321, 323–24).

[78] The preface is printed with the fonts reversed; italic used for the main text and a plain font used for emphasis. In quoting from *Micrographia* I have normalized the fonts so that italic is used for emphasis throughout.

[79] Carl M. Selkin, 'The Language of Vision: Traherne's Cataloguing Style', *English Literary Renaissance*, 6 (1976), 92-104 (pp. 96–97).

appear and come under View all at once that the Eye may the more quickly pass over it from one Particular to another'.[80] He further explains that the contracting of natural history into 'as little Space as is possible', 'is of huge Use in the Prosecution of Ratiocination and Inquiry, and is a vast help to the Understanding and Memory, as in Geometrical Algebra, the expressing of many and very perplex Quantities by a few obvious and plain Symbols'.[81] Hooke's method of bringing together data and ordering it appropriately serves to render it in a visually simultaneous form, thematically grouped and abbreviated, the perusal of which will reveal patterns and suggest axioms and theories. While no account of Hooke's mysterious 'Philosophical Algebra, or an Art in directing the Mind in the search after Philosophical Truths', is found in the essay, this method of aggregating, reducing to symbols, and ordering data seems very suggestive of his intentions to provide a method for Philosophical Algebra, 'which explains the way of making use of the *Penus Analytica*, of raising Axiomes, and more general Deductions from a sufficient Stock of Materials collected according to the Method of this first part, with Integrity, Judgment, and Care.'[82]

Lorraine Daston's recent work on early modern weather watching explores these ideas as they appear in practice in weather tables. Her thesis is that:

> Positioned midway between text and image, the table was a device of synopsis, of "seeing together", which, it was hoped, would reveal subtle correlations between all manner of variables: the fluctuations of the barometer; the phases of the moon; the outbreaks of diseases; the advent of storms.[83]

Daston considers the recording practices of early Royal Society and *Académie Royale des Sciences* members who were engaged in weather watching. Hooke was a driving force of this effort and provided instructions both for conducting observations and for the recording of data in tables, his own exemplary table, which fit on one page, entitled,

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[80] *Posthumous Works*, p. 63.

[81] Lotte Mulligan, 'Robert Hooke and Certain Knowledge', p. 156; *Posthumous Works*, p. 64. Note the contradictory values in the metaphors 'huge' and 'vast' in describing the use of this 'little' space. As in the prefatory material to *Micrographia*, Hooke reassigns the comparative values of size.

[82] *Posthumous Works*, pp. 6, 61.

[83] Lorraine Daston, 'Super-Vision'. This quotation is taken from the abstract; other references in this paragraph are to Daston's talk.

'A Scheme At one View representing to the Eye the Observations of the Weather for a Month' (see Fig. 1.8).[84] Hooke's idea appears in Sprat's *History*:

> Now that these [particulars] [...] may be registred so as to be most convenient for the making of comparisons, requisite for the raising *Axioms*, whereby the Cause or Laws of Weather may be found out; It will be desirable to order them so, that the Scheme of a whole Moneth, may at one view be presented to the Eye.[85]

The use of such tables enabled practitioners to test correspondences and to gather together information from across space and time. Daston connects the use of tables to the urge of early modern science to make the invisible visible (by means of the microscope amongst other methods). Particularly focussing on the idea of presenting data 'at one view', she describes the table as a method of discovery, a technique of visualization aimed at assisting the mind's eye. The primary function of the table is to help the practitioner to see. Similarly, Mulligan writes that she believes it likely that Hooke 'envisaged his "Philosophic Algebra" literally as an "instrument" of discovery'.[86]

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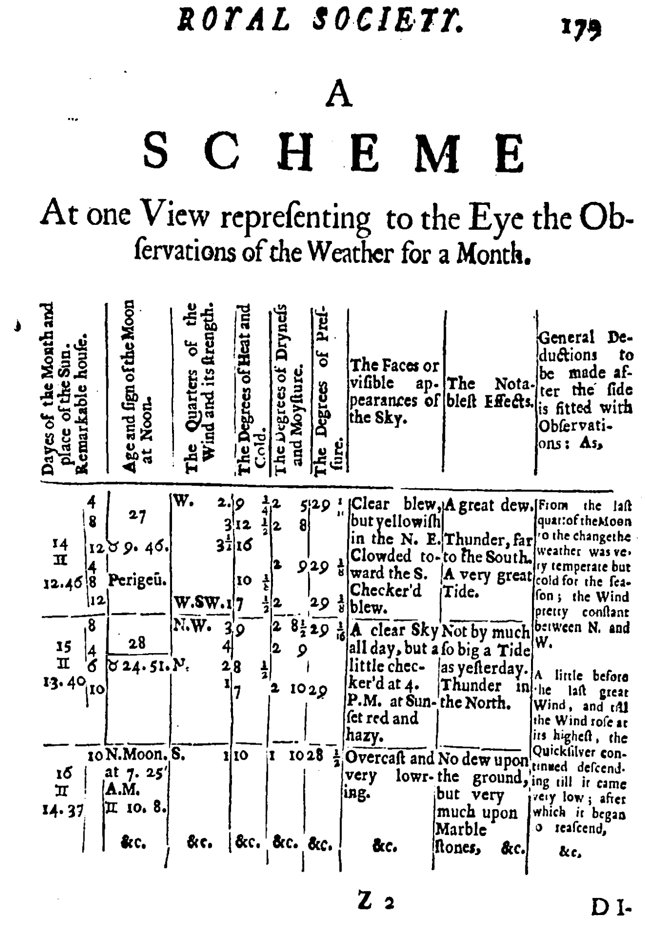
[84] Hooke presented two papers on making a history of the weather (the first undated, the second from October 1663), see London, The Royal Society, Classified Papers, 20/2 and 20/24. A version of this content appears in Thomas Sprat, *The History of the Royal-Society of London, for the Improving of Natural Knowledge*, (London: J. Martyn and J. Allestry, 1667), pp. 173–79.

[85] Sprat, p. 175.

[86] Mulligan, 'Robert Hooke and Certain Knowledge', p. 163.



ROYAL SOCIETY. 179

A
SCHEME
At one View repreſenting to the Eye the Obſervations of the Weather for a Month.

Dayes of the Month and place of the Sun. Remarkable houſe.	Age and ſign of the Moon at Noon.	The Quarters of the Wind and its ſtrength.	The Degrees of Heat and Cold.	The Degrees of Dryneſs and Moyſture.	The Degrees of Preſſure.	The Faces or viſible apearances of the Sky.	The Notableſt Effects.	General Deductions to be made after the ſide is fitted with Obſervations: As,
4 8 14 ♊ 12.46 12 4 8 12	27 ♉ 9. 46. Perigeũ.	W. 2. 3 3½ W.SW.1	9 ¼ 12 ½ 16 10 ½ 7 ½	2 5 2 8 2 9 2	29 1/11 29 ⅛ 29 ⅜	Clear blew, but yellowiſh in the N. E. Clowded toward the S. Checker'd blew.	A great dew. Thunder, far to the South. A very great Tide.	From the laſt quar: of the Moon to the change the weather was very temperate but cold for the ſeaſon; the Wind pretty conſtant between N. and W.
8 15 4 ♊ 6 13.40 10	28 ♉ 24. 51.	N.W. 3 4 N. 2 1	9 8 ½ 7	2 8½ 2 9 2 10	29 1/16 29	A clear Sky all day, but a little checker'd at 4. P.M. at Sunſet red and hazy.	Not by much ſo big a Tide as yeſterday. Thunder in the North.	A little before the laſt great Wind, and till the Wind roſe at its higheſt, the Quickſilver continued deſcending till it came very low; after which it began to reaſcend,
10 16 ♊ 14.37	N.Moon. at 7. 25′ A.M. ♊ 10. 8.	S. 1	10	1 10	28 ½	Overcaſt and very lowring.	No dew upon the ground, but very much upon Marble ſtones,	
	&c.	&c.	&c.	&c.	&c.	&c.	&c.	&c.

Z 2 DI-

Fig. 1.8. Thomas Sprat, *The History of the Royal-Society of London* (London, 1667), p. 179 (cropped).
Photo: © The Huntington Library, San Marino, California.

In *Micrographia* there are no tables, but there are *mise en page* effects and illustrations, which can be understood in terms of visual arrangement being used as a tool or method for understanding data and developing knowledge. In particular I wish to consider the illustrations from the point of view of collating and organizing data 'at one view'.

The first question that needs to be asked is what are the illustrations doing? What is their status and purpose? In his essay on early modern illustrations of natural philosophy, Willem Hackmann describes five categories of image: 1) allegorical title-pages and frontispieces; 2) 'illustrations of the actual experimental configurations described in the text which produced the phenomena in question'; 3) '*actual* observed phenomena produced by the instruments'; 4) diagrams of the supposed underlying structure of phenomena; and 5) graphs.[87] Bizarrely, the single image from *Micrographia* considered in Hackmann's paper — the head of the drone fly in Scheme 24 (see Fig. 1.2) — is categorized as being a type 2 illustration, despite there being no depiction of the experiment, the apparatus, or the conditions of the observation (it is not even obvious that we are looking at an illustration of a severed head rather than the face of an intact insect unless we read the corresponding text of page 175 which tells us this is so). Hackmann refers back to the image when discussing type 3 illustrations: 'As was the case with Hooke's microscope observations, the phenomena made visible by the instruments had to be interpreted and made accessible to a larger audience'.[88] However, he does not consider the image to fall into the third category of observed phenomena, which would be its more obvious assignment. This suggests some confusion regarding the status of Hooke's illustrations. Hackmann does not explain his categorization explicitly but he quotes the passage from signature f2^{v} of the preface, which describes the process of making the illustrations, and observes that 'The artist remained of necessity closely involved in this process', and that 'The techniques of the artist were used to make the image representational'.[89] There seems to be a closeness between the acts of observation and representation which blurs the line between them in Hackmann's interpretation; representation or recording is co-opted as a part of the experiment itself. This confusion is perhaps compounded by elements of visual rhetoric in *Micrographia* that seek to reproduce the experience of microscopical use and encounter for the reader, such as the use of the largest type faces for the phrases 'MICROGRAPHIA' and 'MINUTE BODIES' on the title-page, the fold-out plates of hyperbolically enlarged specimens, and the round frames used for some of the images.

Hackmann's unusual categorization would be unremarkable as more than a quirk of modern criticism if it were not for its coincidence with the status Hooke's microscopical illustrations seemed to have amongst his contemporary Royal Society members. As Curator of Experiments, Hooke was expected to set up experiments to be performed in front of the other members at the Society's weekly meetings. And yet, when he was ordered to undertake the project of producing a collection of microscopical observations, and 'to bring in at every meeting one Microscopical observation at least',

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[87] Willem D. Hackmann, 'Natural Philosophy Textbook Illustrations 1600–1800', in *Non-Verbal Communication in Science*, ed. by Mazzolini, pp. 169–233 (pp. 171–72).

[88] Hackmann, p. 186.

[89] Hackmann, pp. 182, 183.

he never (and never seems to have been asked to) set up a sample under a microscope for members to view, but rather brought with him his drawings.[90] The checks of communal witnessing and discussion were not performed by members viewing the microscopical slides themselves, but by their communal viewing of Hooke's illustrations alone. On the rare occasions where the Society's approval was withheld, this seems to have been based on internal evidence of the drawings themselves rather than comparison with a microscopical sample. Neri describes a picture of a six-eyed spider that was rejected as it 'was not yet perfectly drawn'.[91] In this way, the images take on some of the status of the experiment or act of observation (Hackmann's type 2) in themselves, at the same time as being a record of data, of observed phenomena produced by the instrument (Hackmann's type 3). This echoes Hooke's incorporation of recording and reviewing data into the method of developing knowledge as outlined in the preface to *Micrographia* and the essay on the 'General Scheme', as well as his analogy between learning to write and draw and learning to observe nature in Observation 1. This is perhaps not just a pretty metaphor. In the preface, Hooke describes the difficulties in determining the truth of what is seen through the microscope: 'For it is exceeding difficult in some Objects, to distinguish between a *prominency* and a *depression*, between a *shadow* and a *black stain*, or a *reflection* and a *whiteness in the colour*' (sig. f2^{v}). This is reminiscent of Galileo's great discovery of the uneven surface of the moon in 1610. Galileo was able to interpret the spotted appearance of the moon as the shadows caused by protrusions on an irregular surface in part because of his experience as a draftsman and drawing teacher.[92] Perhaps the act of drawing the microscopical image itself played a part in understanding what was being observed, and conversely if a microscopical sample wasn't properly seen and understood it could not be adequately drawn.

Thinking about the status of Hooke's illustrations as being a part of experiment or observation and having a role in knowledge production (as opposed to just dissemination), suggests that Hooke's methodological principles of ordering data and presenting it 'at one view' may also apply to his microscopical illustrations. To think

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[90] Thomas Birch, *The History of the Royal Society of London for Improving of Natural Knowledge […]*, 4 vols (London, 1756–57), I, 215.

[91] Birch, I, 231, quoted in Neri, p. 109.

[92] Samuel Y. Edgerton, *The Mirror, the Window, and the Telescope: How Renaissance Linear Perspective Changed our Vision of the Universe* (Ithaca: Cornell University Press, 2009), pp. 9–10.

about the images in this way, one must acknowledge that the notion of Hooke as the amanuensis of the microscope is an illusion. There is an astounding difference between the clearly defined illustrations of *Micrographia* and Brian Ford's modern photographic reproductions of the unclear, distorted, partial views of insects through the sorts of microscopes used by Hooke and his contemporaries.[93] Although Hooke presents himself as 'peeping in at windows', this is an idealized vision of the gathering of knowledge and does not accurately describe his practice.

Neri's work in particular reveals the layers of interpretation and conscious presentation in Hooke's images. She notes discrepancies between Hooke's notes and his published work, which suggest the reframing of experience for rhetorical ends. She writes of the disjunction between the textual description of dissections and dismemberments in Hooke's observations, and the illustrations of perfectly intact specimens. Neri describes how Hooke, in order to ennoble the blue fly specimen of Scheme 26 (see Fig. 1.6), 'carefully conceal[s] the destruction of its body that was necessary to observe it', and, describing the illustration of the louse in Scheme 35 (see Fig. 1.1), writes: 'In the engraving, Hooke uses the transparent membrane of the insect's body as a window to its internal structures, thereby uniting in a single image information gained through dissection with observations of the creature's external appearance.'[94] Neri uses her shrewd observations to further an argument about the othering of insects as specimens and the role this commodification of nature played in the constructing of the esteemed persona of the scientist as gatekeeper. I think her observations about the constructedness of Hooke's illustrations can also be used to support a reading of those images being a part of Hooke's method of developing knowledge by presenting aggregated data 'at one view'.

In creating the images for *Micrographia*, Hooke employed engravers whom, he assures the reader, 'have pretty well follow'd my directions and draughts' (sig. f2^{v}). Hooke describes his drafting practice thus:

> In making of them, I indeavoured (as far as I was able) first to discover the true appearance, and next to make a plain representation of it. This I mention the rather, because of these kind of Objects there is much more difficulty to discover the true shape, then of those visible to the naked

[93] Ford, *Images of Science*, pp. 182, 183.

[94] Neri, pp. 120, 136.

> eye, the same Object seeming quite differing, in one position to the Light, from what it really is, and may be discover'd in another. And therefore I never began to make any draught before by many examinations in several lights, and in several positions to those lights, I had discover'd the true form. (Ibid.)

Hooke's conception of a 'plain representation', i.e. what he conveys in the illustration, is not actually the same as his view through the microscope. Hooke acknowledges the difficulty of discerning the 'true appearance' of a microscopic subject and so resolves to discover its 'true form' by comparing different views under different lighting conditions and creating a composite of this information. As noted above, Neri demonstrates that these multiple views can include observations of both whole and dissected creatures, and as Aït-Touatì points out, observations of both live and dead specimens.[95]

In his illustrations, Hooke does not just include data from his own multiple observations, but even includes information from other sources — although he does not always admit to such practice. Ford shows that Hooke's illustrations of snowflakes in Scheme 8 (and indeed Hooke's original drawing which, unlike most of the others, has survived amongst his papers at the Royal Society) were not all based on observations from nature, but that five of the snowflakes depicted in Figure 2 were plagiarized from Thomas Bartholin's *De Nivis usu Medico Observationes Variae* (1661).[96] Ford's confidence in his assertion of plagiarism comes from the fact that at least one of the images from *De Nivus* echoed in *Micrographia* was the product of Bartholin's imagination, being too fanciful to have been observed from nature. As with his practice of dissection, Hooke disguises his aggregation of information from various sources, claiming on page 91 that the snowflakes of Scheme 8, Figure 2 are drawn from observation without any mention of Bartholin's book. Harwood notes that in Scheme 27, Figure 3, Hooke reproduces Gulielmus Piso's illustration of an aquatic beehive.[97] In this instance Hooke cites and discusses his source, which perhaps explains why Harwood mistakenly believes this to be the only reproduction of an object Hooke hadn't seen himself. Neri notes similar external influences on the development of Hooke's

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[95] Aït-Touatì, p. 151.

[96] Ford, *Images of Science*, pp. 170–72.

[97] Harwood, pp. 142, 142n. The source is Gulielmus Piso/Willem Pies, *Indiae Utriusque Re naturali et Medici* (Amsterdam, 1658), p. 113.

illustration of the crablike insect in Scheme 33. In Hooke's sketch of this creature in the Covel notebook, the insect has only six legs, but although the accompanying text in *Micrographia* asserts that Hooke had only ever seen the one example 'and so could not make so many examinations of it as otherwise I would' (p. 208), the insect in the published illustration is depicted with eight legs. Neri suggests that Hooke may have included the extra legs, and supplied additional surface detail not recorded in the sketch, based on his knowledge of other insects, such as spiders. She also suggests Piso as a possible source, citing an illustration of an eight-legged crab that has a very similar positioning of the claws in his *Historia Naturalis Brasiliae* (1648).[98] In the text of *Micrographia* Hooke occasionally includes reference to the experiments, publications, and theories of other practitioners. While his sources are not always explicitly acknowledged, it is clear that this practice of aggregating information from the wider scientific community to present it in a composite form occurs in the construction of his illustrations as well.

As well as gathering together data 'at one view' there are also ways in which Hooke's illustrations follow his principles of ordering or organizing data: Hooke's illustrations employ grouping strategies. Harwood has produced a wonderful table giving an approximate chronology of fifty-one of Hooke's observations, showing either a recorded date of observation or the date of presentation to the Royal Society.[99] Harwood uses his table to draw conclusions about the social influences on the evolution of the project, but it also allows him make comments on the organization of the volume. Harwood notes that the order of the observations throughout the book does not follow the chronological order in which the observations occurred, however he also claims that 'similar topics were not always grouped together, unrelated topics (particularly in the earlier schemata) appeared on the same plate'.[100] Harwood does not offer any satisfactory explanations for his observations of 'apparent randomness', suggesting without substantiation that the organization of the volume represents an 'early, data-

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[98] Neri, p. 130–31. Cf. p. 132 (Fig. 4.12) for a reproduction of the image from Gulielmus Piso, *Historia Naturalis Brasiliae* (Amsterdam, 1648), p. 185.

[99] Harwood, Table 1, pp. 124–25, cf. p. 123 for an explanation of the table.

[100] Harwood, p. 137. Harwood also complains that prints were often widely separated from their commentary, but this is irrelevant as the placement of the engraved plates varies in existing copies, most likely at the caprice of the binder or customer.

gathering stage' and was partially determined by the time of year.[101] He focuses instead on Hooke's use of verbal rhetoric to encourage coherence.[102] However, if one rearranges the data from Harwood's table so it is ordered by schema number rather than date, obvious thematic grouping predominates (as it does for the observations which are not datable and thus do not appear on the table). In fact, Harwood's remark about the disruption of chronology actually lends credence to the idea of non-random organization, as it appears observations on related subjects were grouped into one schema even when they occurred months or years apart. For example, the sensible plant and cork, which are both described in Observation 18 and appear in Schema 11, were observed in August 1661 and April 1663 respectively, and two illustrations of petrified wood appear in Schema 10, observed in May 1663 and August 1664.[103] Like the gathering of textual or numerical data under specific subject heads, Hooke presented related figures together in one plate or scheme. The grouping across time suggests that the organization of *Micrographia* was *not* an 'early, data-gathering stage', but rather a product of a later stage of sifting and organizing according to such heads.

This grouping did not just occur in a top-down fashion according to pre-existing notions of what should constitute a set. The blue mould of Observation 20 (see Fig. 1.9) is illustrated in Schema 12 alongside the parasites of rose leaves of Observation 19, depicted in the same plate or scheme (see Fig. 1.10). Mould and leaf parasites might not seem like an obvious grouping, but their illustrations bear a striking visual similarity. As with the use of analogy based on visual comparisons internal to the micro world considered in the previous section, Hooke lets the new data speak to each other and form relations on their own terms instead of forcing assimilation to preconceived ideas from the macro world. This is another way in which visuality is a part of the production of knowledge and not just a conduit for information that is then to be processed separately from the senses.

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[101] Ibid.

[102] Harwood, p. 138.

[103] As well as multiple observations resulting in multiple illustrations as with the samples of petrified wood, there are also examples where multiple observations contribute to a single image, as in the two observations of male gnats on the 6 and 27 May 1663, represented in an illustration of a solo insect in Schema 28 which substantiates the point above about composite images.

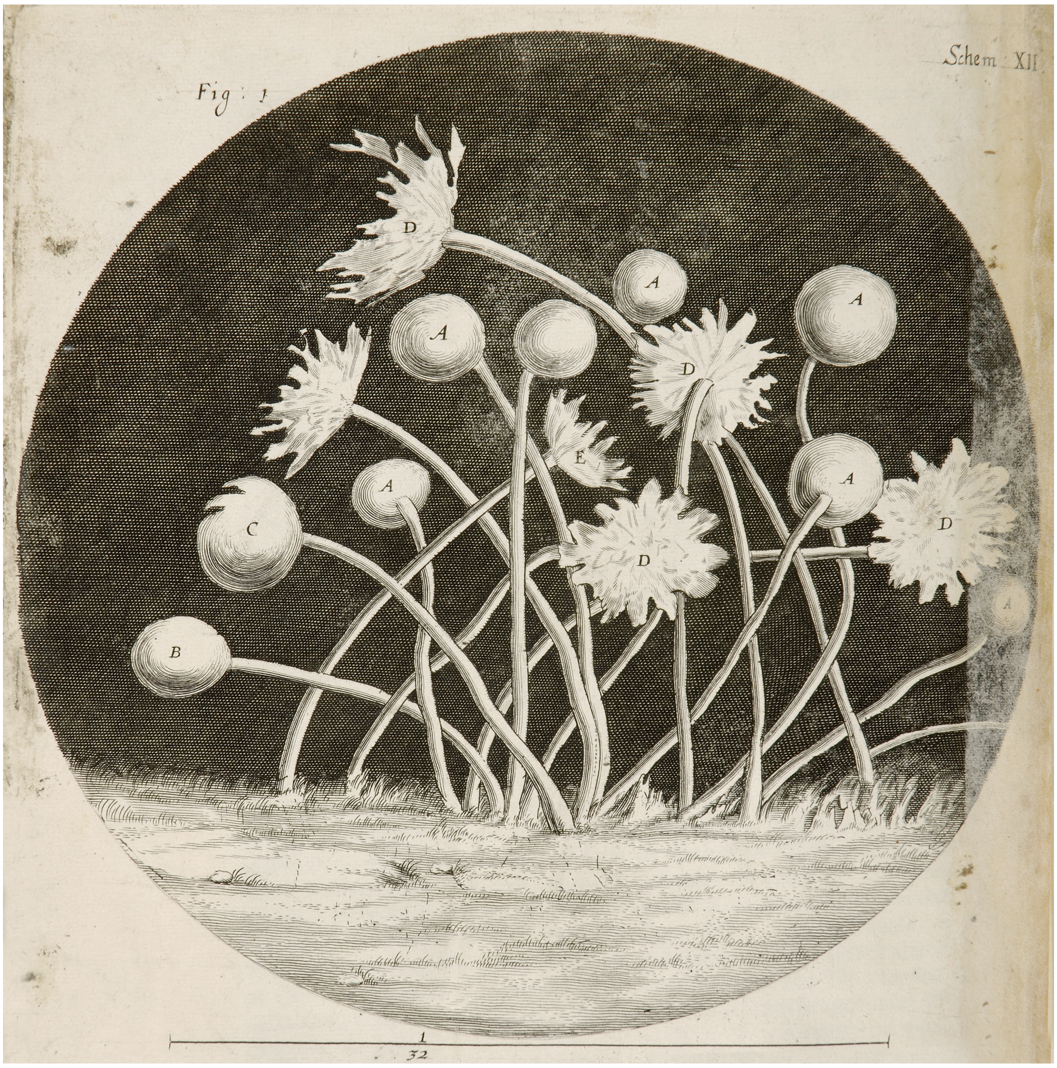

Fig. 1.9. Robert Hooke, *Micrographia* (London, 1665), Scheme 12 (cropped). Photo: RS.5095 © The Royal Society.

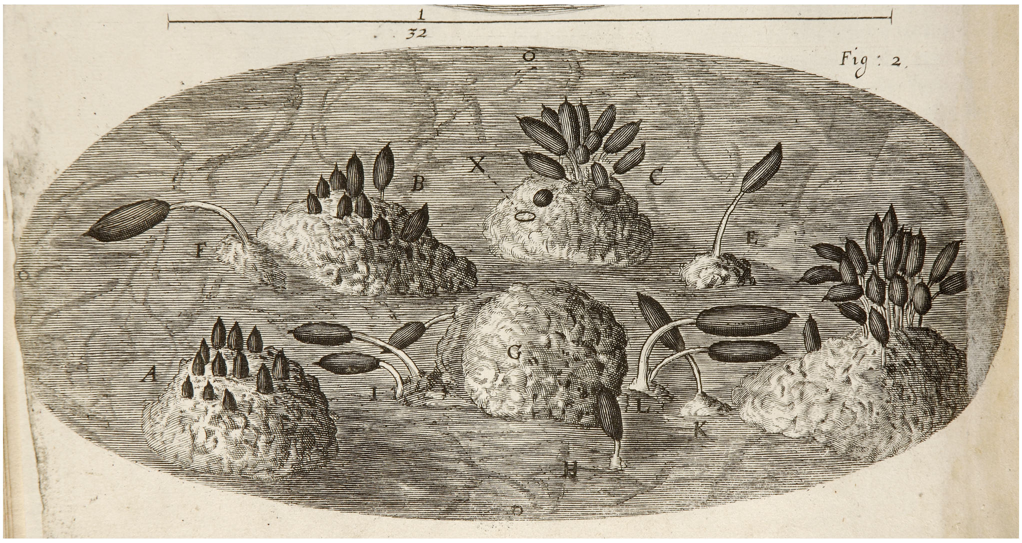

Fig. 1.10. Robert Hooke, *Micrographia* (London, 1665), Scheme 12 (cropped). Photo: RS 5098 © The Royal Society.

Another sort of grouping is also evident in the technique of labelling parts of the images. As well as allowing for a correspondence between image and text, Hooke also groups parts of the image by using the same letter to show correspondence between like parts of the specimen, such as is seen in the illustration of blue mould (see Fig. 1.9) in which there are six A types, four D types, and one each of types B, C, and E. As Aït-Touatì notes, this technique is even used to demonstrate kinetic logic by signifying the coordination of two elements performing a single movement.[104] This last in particular demonstrates how the technique of grouping or ordering contributes to the understanding of how things work. The use of letters again suggests the metaphor of observation as an act of reading.

In the 'General Scheme' essay, Hooke describes the reasons for including pictures and also issues some warnings about their use:

> Now because oftentimes much more may be expressed in a small Picture of the thing, than can be done by a Description of the same thing in as many words as will fill a Sheet; it will be often necessary to add the Pictures of those Observables that will not otherwise be so fully and sensibly exprest by Verbal Description: But in the doing of this, as a great Art and Circumspection is to be used in the Delineation, so ought there to be very much Judgment and Caution in the use of it. For the Pictures of things which only serve for Ornament or Pleasure, or the Explication of such things as can be better describ'd by words is rather noxious than useful, and serves to divert and disturb the Mind, and sways it with a kind of Partiality or Respect: Besides that, it fills up room, and occupies the Mind with the Ideas of things which are little significant in the present Inquiry.[105]

When he considers pictures, Hooke is governed by the same priorities as in the rest of his method for recording information and forming knowledge. He suggests the use of pictures when it will furnish better or more information than a description, particularly where doing so pictorially will take up less room. The importance of observations being 'sensibly exprest' echoes the idea of presenting information to the eye, or indeed 'materially and sensibly'. Hooke's illustrative practices, his inclusion of a high level of

[104] Aït-Touatì, p. 156.

[105] *Posthumous Works*, p. 64.

detail, the aggregation of information from multiple views, the thematic grouping, all suggest that he was following his method, his scientific tool, of recording data ‘at one view’. This approach both follows and embodies Hooke’s epistemological method of collation and comparison of carefully gathered data in order to produce a best guess.

These principles of spatial ordering are not just something that happens on the page though. This practice is, for Hooke, not only integrated into his epistemology, but into his theory of mind. In 1682, Hooke gave a lecture to the Royal Society offering a hypothetical and mechanical explanation of memory, which he conceives as a material organ. As Douwe Draaisma notes, Hooke is the first to quantify and spatialize memory processes (memory having previously been conceived of as non- or *quasi*-spatial).[106] Hooke uses the metaphor of a ‘Repository’ to describe memory, thus linking it to ideas of physical storage space — in particular to the Royal Society’s own ‘Repository’ or collection of objects — and to other less concrete uses of the word *repository* in Hooke’s ouvre to mean the gathering together of data in the natural philosophical enterprise.[107] Hooke also uses the image of the memory as a chain of links and the idea of the mind as a microcosm of the universe. Draaisma shows how these models allow Hooke to quantify the memory and to give the individual ideas within that storehouse a specific location, thus bringing time and memory under ‘the Consideration of Geometry and Mensuration’.[108] Wilding observes that Hooke at no point employs writing (in its usual sense) as a model for memory.[109] Memory is a collection of things — as we learned of Hooke’s theory of perception, an assemblage of moments — and functions entirely by order, by spatial arrangement, which (as we have seen) is a core tool for the production of knowledge in Hooke’s epistemology. As Draaisma writes, ‘Hooke ordered mental processes by acting *as if* they were spatial. Metaphors were the tools he used to create space in a memory that otherwise would have remained closed to the imagination.’[110]

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[106] Douwe Draaisma, ‘Hooke on Memory and the Memory of Hooke’, in *Robert Hooke: Tercentennial Studies*, ed. by Cooper and Hunter, pp. 111–21 (pp. 111, 115).

[107] *Posthumous Works*, p. 138.

[108] Draaisma, p. 115; *Posthumous Works*, p. 141.

[109] Wilding, p. 126.

[110] Draaisma, p. 120.

Conclusion

Hooke was engaged in a programme of natural philosophical investigation with the intention of 'rectifying the operations of the *Sense*, the *Memory*, and *Reason*'. He looked to instruments to aid him in this. This included not only instruments such as lenses to widen the scope of the senses, but also graphic technologies and data gathering standards and methodologies to externalize and reliably collectivize memory as data, and to order it in such a way that from it knowledge could be produced. Hooke's epistemological principle of incremental knowledge — which acknowledged uncertainty and admitted hypotheses on a contingent basis — allowed knowledge to grow more rapidly, but without weakening its certainty, and also allowed for a more genuine exploration of the new worlds his microscope discovered, on their own terms.

The centrality of space and spatiality to his quest is without doubt. Hooke's methods are empirical and rooted in observation, particularly visual observation. However these views are not innately comprehensible in the sense of being able to just see and know. The microscopist is not an amanuensis for his scope, but must read nature in the sense of interpreting it with experience and judgement. As such the spatiality of Hooke's epistemology becomes more than the simple translation of visuality at different levels of magnification, it becomes relational and schematic, making patterns, those connections of reason, across time and space. By considering the spatiality of Hooke's natural philosophy at this meta level and in this more structural way, we can understand better the ways in which he creates relations between — and indeed within — the macro and micro worlds. Hooke uses existing knowledge to approach and understand the unknown by means of various analogies, but also resists an assimilative approach by reflecting new knowledge back onto the old to disrupt existing assumptions, by looking for internal patterns within the unknown, and by allowing uncertainties to remain. He creates a dialectic of relativity between the worlds that relies on connection and pattern. Finally, in the way in which Hooke presents his data on the page — in tables, lists, themed groups, and composite illustrations — he uses spatial ordering to gather data together, across time and space, and at one view, to aid the natural philosopher in seeing patterns and reading axioms from it, and thus producing knowledge.

Chapter 2

Robert Boyle and Air

Fig. 2.1. Robert Boyle, *New Experiments Physico-Mechanicall, Touching the Spring of the Air and its Effects* (London, 1660), plate 1. Photo: RS.9913 © The Royal Society.

Introduction

On turning to the works of Boyle after considering Hooke's *Micrographia*, one cannot help but be aware of the comparative lack of visual impact Boyle's oeuvre offers. In the fourteen volumes that make up Michael Hunter and Edward Davis's edition of *The Works of Robert Boyle*, just twenty-eight plates and in-text illustrations are to be found amongst the entire corpus of Boyle's publications.[1] And yet the themes of visuality and spatiality in Boyle's work on air, while more subtle, are of no less interest in understanding his methods and epistemology. In Hooke's work we saw the reconceptualizing of the everyday experience of macro space to include a subvisible micro world newly discovered by lenses — a new space at a different scale within the old space. In Boyle's work on the particulate air we find a similar zooming in to concentrate on space at a more minute scale, however this zooming is not optical, but mental; Boyle does not accommodate a newly visible world, but rather an invisible and indeed hypothetical one — an idea of space.

In *Micrographia*, all but one scheme (see Fig. 1.3 detailing the microscope) offered the reader face-to-face encounters with the scientific object itself. Across Boyle's ouvre, by contrast, almost all of the illustrations are of, or at least feature, the instruments used in his experiments, such as the air pump and other related apparatus illustrated in *New Experiments Physico-Mechanicall, Touching the Spring of the Air and its Effects* (1660)[2] (see Fig. 2.1). The exceptions are an illustration of the '*Monstrous Head*' of a deformed colt accompanying an observational description in *Philosophical Transactions* (3 July 1665); two marginal diagrams showing barometric readings in *The General History of the Air, Designed and Begun by the Honourable Robert Boyle Esq.* (1692);[3] and two figures (in a plate with four others depicting apparatus) in *A Defence of the Doctrine Touching the Spring and Weight of the Air* and *An Examen of Mr T. Hobbes his Dialogus Physicus De Natura Aeris* (1662)[4] illustrating atomic and mathematical concepts, but referring to a part of the text written by Hooke

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[1] *The Works of Robert Boyle*, ed. by Michael Hunter and Edward B. Davis, 14 vols (London: Pickering & Chatto, 1999–2000). Further references are to this edition and are given by volume and page number parenthetically in the text.

[2] Hereafter *Spring of the Air.*

[3] Hereafter *General History of Air.*

[4] Published as a pair and sharing a plate. Hereafter *Defence* and *Examen*.

(see Fig. 2.6).[5] Of the instrumental illustrations, only a third (seven plates from *A Continuation of New Experiments Physico-Mechanical, Touching the Spring and Weight of the Air, and their Effects. The First Part.* (1669)[6]) depict actual experimental set ups rather than generic apparatus. As is suggested by this illustrative interest, and as I explore in the rest of this chapter, in Boyle's work, it is not magnification, but rather the demarcation of experimental spaces, both physically and mentally, which allows access to and the study of a new world that yet remains invisible.

In Hooke's work we also saw that the visual and spatial presentation of natural philosophical data played an important role in the development of knowledge: from the detailed composite illustration of new phenomena, to the gathering 'at one view' of other types of data in tables or under headings to understand systemic relationships. These impulses to visualize and aggregate are also to be found in Boyle's method, but in quite different ways. Boyle's visual instincts lean more towards creating mental imagery rather than pictorial illustrations of the phenomena under examination. This allows for more malleable images capable of both capturing the motions required for understanding the subvisible mechanical world, and of accommodating Boyle's insistence on the hypothetical nature of his imagery. Similarly, while he also aggregates information with a view to understanding nature as a whole and makes some attempts at ordering such information — including use of tables for numerical data (including weather data) in his published works and attempts at common placing in his notes — there is also a degree of chaos to Boyle's work and presentation that seems to reflect a resistance to the imposition of an artificial order or system. As I explore in this chapter, Boyle's primary use of spatiality is about creating spaces in which to experiment, observe, and think. In this introductory section, I briefly outline some of Boyle's key views on the capacities, remit, and purpose of human knowledge and natural philosophy before considering some of the epistemological questions raised by the study of air and the roles of visuality and spatiality in Boyle's response to this quandary. As in the previous chapter, this prepares the ground for a consideration of Boyle's conception of the legibility of nature, how he depicts the relationship between the visible and invisible worlds, and his methods of verbally and visually presenting his findings.

[5] The illustrations are reproduced in *Works*, V, 498; XII, 89; XII, 91; III, 16.

[6] Hereafter *Spring, 1st Continuation*.

In *A Discourse of Things above Reason. Inquiring Whether a Philosopher Should Admit There Are Any Such* (1681),[7] Boyle authors a debate between four characters as to '*how far*, we may employ our reasonings about things that are above our Reason' (IX, 365). The dialogue has a particular focus on the mysteries of the Christian religion but often uses images and ideas from natural philosophy and mathematics, and reveals much of Boyle's thought on the capacities of human knowledge in general. Sophronius, Boyle's mouthpiece, advocates that human reason is limited, but that it can comprehend its limits. Boyle defines three categories of things that are above reason: the '*Unconceivable*' where the mind is too limited to have a 'clear and full comprehension of them'; the '*Inexplicable*', for things 'which we cannot perceive to depend upon [i.e. be caused by] the *Idœas* we are furnished with'; and the '*Unsociable*', for things which seem to result in incongruities or inconsistencies with our existing knowledge (IX, 388). He illustrates the limitedness of human reason by demonstrating its lack of capacity to comprehend mathematical or physical truths, such as the infinite divisibility of a line (IX, 378). As Jan Wojcik subtly observes, Boyle does not in this text commit himself to the exact nature of the limitedness of human reason, but he most often appeals to the difference between God's infinite and man's finite reason to support his argument.[8]

There is a spatiality to the difference between the reason of God and that of man, which (as we saw in Hooke's depiction of the defects in fallen human understanding) is framed by Timotheus in the language of proportion:

> the means or measures which are furnished us to employ in the searching or judging of Truth, are but such as are proportionable to Gods designs in creating us, and therefore may probably be supposed not to be capable of reaching to all kinds, or if you please of Truths, *many* of which may be unnecessary for us to know here, and some may be reserved, partly to make us sensible of the imperfections of our Natures, and partly to make us aspire to that condition, wherein our faculties shall be much enlarged and heightned. (IX, 371)

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[7] Hereafter *Things above Reason*.

[8] Jan W. Wojcik, 'The Theological Context of Boyle's *Things above Reason*', in *Robert Boyle Reconsidered*, ed. by Michael Hunter (Cambridge: Cambridge University Press, 1994), pp. 139–55 (p. 141). For a full analysis of this complex work, see also Jan W. Wojcik, *Robert Boyle and the Limits of Reason* (Cambridge: Cambridge University Press, 1997).

The language used to express the comparison between divine and human reason (*measures*, *proportionable*) is the language of geometry and invokes a metaphor of visual proportion (*enlarged*, *heightned*) to illustrate the comparison. This metaphor also opens up possibilities beyond a strict binary of human and divine, spatiality allowing the idea of a continuum along which we can progress. Although *enlarged* and *heightned* are in the passive voice suggesting the expansion of the faculties is at the hand of God, *aspire* is active and captures a sense of human endeavor as part of the process.

It is also interesting to note that although our faculties are proportional to God's design for us, and thus limited — perhaps not even capable of reaching to Truths — we are still furnished 'for the searching and judging of Truth'. This quotation expresses some of the purpose of limited human knowledge: to make us aware of what we do not know and to make us aspire beyond that, which fits both with a rhetoric of wonder and worship of God, and with a language of measurability and active natural philosophical enquiry. It suggests both humility and possibility at the same time, and like the conceptual difficulty of the infinite divisibility of a line, expresses the sense of wonder at the unknown within a framework that offers some related structure for approaching it.

This sense of aspiration and the worth of contingent knowledge is also found in Boyle's approach to practical matters of experiment. For example in Experiment 6 of *Spring of the Air*, Boyle writes:

> And though we were not provided of Instruments fit to measure the dilatation of the Air any thing accurately, yet because an imperfect measure of it was more desireable then none at all, we devis'd the following Method as very easily practicable. (I, 176)

An imperfect measure is still of value, and in this way knowledge is treated as cumulative and progressive. In *Spring of the Air* Boyle quotes Horace: '*Est quoddam prodire tenus, si non datur ultra*' ('It is worthwhile to go so far, even if we cannot go further') (I, 243).[9] Like the Horatian couplet on the title page of *Micrographia*, this tag, again cast in terms of spatial metaphor, emphasizes the relative value of even limited knowledge.

In *Things above Reason*, when Sophronius explains how reason works he also uses a language of measurement:

[9] Hunter and Davis's translation.

> Reason operates according to certain Notions or Ideas, and certain Axiomes and Propositions, by which, as by Prototypes or Models, and Rules and Measures, it conceives things, and makes estimates and judgments of them. (IX, 375)

Reason works empirically, by measurement, by cataloguing, by judging the new experience against existing knowledge, which although potentially requiring of certainty (the use of *certain* is here ambiguous) does include 'Notions', 'Ideas', and 'Propositions', as well as 'Axiomes'. There is also a sense in which this is spatial. Boyle defines philosophical reason in the *Appendix* to *The Christian Virtuoso*,[10] 'not as a faculty [...] but as she manages a frame or system of ideas and propositions', the image of a *frame* or *system* suggesting a map of relations (determined by reason) between objects (XII, 422). However, in *Things above Reason* Boyle's protagonist also considers that such rules and notions may be 'useless or deceitful to us' if we 'stretch them beyond their measure, and apply them to the infinite God, or to things that involve an Infiniteness either in multitude, magnitude, or littleness' (IX, 375). So although there is both a horizontal sense of spatial structure to knowledge and reason, and a vertical one with increasing levels of knowledge and a value placed on upward progression and aspiration, there is also a sense in which proportionality breaks down as a concept when applied to ideas — both spiritual and mathematical — beyond measure. Boyle's work on air sits somewhere along this boundary, requiring a mental zooming in of space to conceive of tiny particles that are sometimes depicted as finite and fixed of size, and at others as infinite and infinitely small.

The disproportion between God's reason and human measure offers a challenge to the value of human knowledge, and by extension the natural philosophical project. For example in *Some Considerations touching the Usefulnesse of Experimentall Naturall Philosophy. The First Part* (1663),[11] Boyle asks why God, 'whose Knowledge infinitely transcends ours, and who may be suppos'd to operate according to the Dictates of his own immense Wisdom', should, in his creation, 'have respect to the measure and ease of Humane Understandings'? Boyle concludes, 'that way may often

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[10] Ed. by Henry Miles, first published in *The Works of the Honourable Robert Boyle*, ed. by Thomas Birch, 5 vols (London: A Millar, 1744).

[11] Hereafter *Usefulness, I.*

be fittest or likeliest for Nature to work by, which is not easiest for us to understand' (III, 257). However, in *Things above Reason*, Sohpronius asserts that 'it is not an injury to reason to think it a limited faculty' and demonstrates the high esteem he holds for human reason: 'I assign Reason its most noble and genuine Exercise, which is to close with discovered Truths' (IX, 371). Humanity might not be the measure of Godly wisdom, but it is furnished to close with discovered truths. Similarly, Timotheus says of natural philosophy:

> Thus we usefully study the nature of Bodies, which make up the Object of the Excellent Science of Natural Philosophy; though the true Notion of Body in general be a thing so difficult to frame, that the best of our Modern Philosophers can by no means agree about it. (IX, 391)

There is a 'true notion of body' that is elusive to philosophers, but the enterprise is still useful and excellent. While Boyle does hold that human knowledge is limited, he does not diminish the value of seeking knowledge, nor does he question the capacity of man to know things of a mechanical nature, even if he may not presume to understand their ultimate cause.

I now wish to consider the specific difficulties faced by Boyle in one of his major experimental concerns — the natural philosophical study of the air. When thinking of air, one immediately runs into conceptual difficulties to do with its transparency. How do we conceive of it? Do we imagine air to constitute or to be located in space? Do we think of it as matter? As nothing? Even in our post-Newtonian world where we know the air to be made up of atoms and where we commonly adopt the atomic position when the make up or pressure of the air comes under discussion, we default to a mode that forgets the existence of this invisible, imperceptible, ubiquitous substance, as testified to by the use of the word *empty* which rarely includes the idea of being empty of air. The seeming unnaturalness of the idea of the substantiality of air is captured in Evangelista Torricelli's famous assertion in a letter to Michelangelo Ricci of 11 June 1644: '*Noi viviamo sommersi nel fondo d'un pelago d'aria*' ('We live submerged at the bottom of an ocean of air').[12] Some of this strangeness is perhaps felt in Boyle's frequent use of the term 'Ambient Air', which seems to express a need for an assertion of its environing quality.

Boyle in *Spring of the Air* offers his corpuscularian hypothesis for its make up:

> That our Air either consists of, or at least abounds with, parts of such a nature, that in case they be bent or compress'd by the weight of the incumbent part of the Atmosphere, or by any other Body, they do endeavor, as much as in them lies, to free themselves from that pressure, by bearing against the contiguous Bodies that keep them bent; and, assoon as those Bodies are remov'd or reduced to give them way, by presently unbending and stretching out themselves, either quite, or so far forth as the contiguous Bodies that resist them will permit, and thereby expanding the whole parcel of Air, these elastical Bodies compose. (I, 165)

The hypothesis is by no means certain and Boyle offers the either/or of the air consisting of or abounding with particles, but, although unseen, it is clear that he is thinking of air — or the parts of air — in material and mechanistic terms. When Boyle writes of 'the whole parcel of Air, these elastical Bodies compose', he is explicit in thinking of the particles of air themselves as bodies, and the phenomenon of elasticity or spring is explained in terms of the interaction between such bodies — either air particles and other air particles, or air particles and other compressing bodies.

It is in this idea of mechanical interaction that we find the means to observe the air. Although the increased granularity of the microscopical view offered analogous ways of conceiving of the air as tiny particles, it could not make the components of air visible. Practitioners instead followed a different process. They conducted experiments on visible objects and made observations on phenomena such as inflated bladders or extinguished candles. From these observed effects, they could then make inferences about the behavior of air, and thus hypothesize about its nature.

In *Things above Reason,* Boyle's antagonist, Pyrocles, uncomfortable with Sophronius's notion that human reason is limited (and indeed that Sophronius uses

[12] Quoted and translated in Gabrielle Walker, *An Ocean of Air: A Natural History of the Atmosphere* (London: Bloomsbury, 2008), p. 18. Hooke also uses this metaphor in 'General Scheme', see Hooke, *Posthumous Works*, p. 63.

reason to argue for this, i.e. using reason to limit reason), challenges:

> ’tis strange to me, how you would have our Reason comprehend and reach things, that you your self confess to be above Reason, which is methinks, as if we were told that we may see things with our eyes that are invisible. (IX, 371)

Pyrocles frames his dilemma about the seeming incongruity of comprehending things above reason in terms that echo the paradox of the natural philosopher attempting to observe the invisible air. However, Pyrocles’s sceptical comment appears in a work that follows two decades of publications by the author that address precisely that dilemma. Several pages later, Sophronius’s response returns to Pyrocles’s analogy: ‘we do not pretend that the Eye of the Mind should see Invisibles, but only that it shall discern the limits of that Sphere of Activity, within which Nature hath bounded it, and consequently that some Objects are disproportionate to it’ (IX, 383). There is a spatialized and suggestively airy quality to Boyle’s imagery of invisibles discernible by bounds and limits. There is a subtle distinction between *see* and *discern*. Like the object air in his experiments — separated and demarcated by the glass of the air pump’s receiver, its motions discerned by its effect on visible bodies, and the skin of a bladder marking in negative its invisible boundaries — reason and the non-specific image of ‘Invisibles’ are discerned by inference from their bounds and limits, at the same time as recognizing the sense of disproportion implicit in this discernment. There is also the intriguing image of the ‘Eye of the Mind’; the sphere of activity, of vision, has moved from the bodily eyes into the mind, and yet we are told this eye does not see, it only discerns. The metaphorical sight of the visual imagination itself becomes a metaphor for a subtly different form of perception, emphasizing how imbricated vision is with knowledge, and evoking the mental ‘seeing’ that occurs in Boyle’s experimental practice.

The other key component in making air or the effects of air ‘visible’, is space. More specifically: demarcated, controlled, experimental space. As Steven Connor observes, studying the air turns it into — indeed depends on it being — an object. In order to achieve this it must be partitioned: ‘In order to be seen and known as itself, air had to be divided from itself.'[13] After all, 'How was the air to be picked out of its surroundings, when air was ambience itself? [...] An object [...] must exist in a space of observation.'[14] Boyle achieved this partitioning and objectification with his air pump (see Fig. 2.1), a device that marked off the air of the experimental space from the ambient air in a hermetically sealed glass receiver, out of which air could be sucked in order to rarefy the contained air or create a vacuum (or an approximation thereof). The sense of demarcation is felt in Boyle's language:

> But it seem'd that in so little a Receiver, *the Air about the Viol* being suddenly drawn out, *the Air Imprison'd in the Vessel*, having on it the whole pressure of the Atmosphere […] and not having on the other side the wonted pressure of *the Ambient Air* to ballance that other pressure, […], *the external Air* might rush in with violence. (I, 181–82, my emphasis.)

Boyle takes pains to make it clear to which portion of air he is referring at each moment.

There is an extensive concern in Boyle's works on air with the integrity of the observational, experimental space. This concern is manifest in the focus of the illustrations and the prolix descriptions of the apparatus, which help conjure a secure image of the experimental space in the reader's mind, and of the extensive discussion of attempts to counter the common problem of leakage. The problem of leakage was not just a practical problem, but an epistemological one as well. As Steven Shapin and Simon Schaffer note, 'the physical integrity of the machine was vital to the perceived integrity of the knowledge the machine helped to produce.'[15]

There are two kinds of knowledge that are produced by this sort of experimentation: data (the observations made and recorded) and hypothesis (theoretical explanations for the observed phenomena). Like Bacon and Hooke, Boyle values observational data as the foundation of natural knowledge. Boyle shows his confidence in producing evidence for his hypotheses from experimental procedures by making no

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[13] Steven Connor, *The Matter of Air: Science and the Art of the Ethereal* (London: Reaktion Books, 2010), p. 16. On the objectification of air, see also idem, 'Next to Nothing: The Arts of Air' (2007), <http://www.stevenconnor.com/airart/airart.pdf> [accessed 2 November 2009] (p. 8).

[14] Connor, 2010, p. 17.

[15] Shapin and Schaffer, p. 30.

apology in *Spring of the Air* for omitting the authority of other philosophical authors, 'the Experiments of our Engine being themselves sufficient to hint such Notions as we build upon them' (I, 145). Also like Hooke, Boyle views hypothesis as an important tool in the development of knowledge, but even more than Hooke, he emphasizes the contingent and uncertain status of such ideas, cleaving firmly to an epistemology of nescience. As mentioned above, in *Things above Reason*, Boyle warns against the deceitfulness of applying our own measure to 'things that involve an infiniteness either in multitude, magnitude, or littleness', an idea which may well apply in some degree to the concept of atoms which were conceived of variously as infinitely small and as the smallest parts of nature.

In *Spring of the Air*, Boyle describes both his own theory for the elasticity of the air and the competing theory of Descartes, saying: 'I am not willing to declare peremptorily for either of them, against the other' (I, 166). He acknowledges that neither hypothesis 'gives us a sufficient account of its Nature' (I, 167) — that is, although mechanical observations can be made, the underlying cause is still unknown. As such, he refuses to declare for either, even though one is his own and clearly as such, his preferred theory. In the conclusion to the same work, Boyle applies the words of Augustine's nescience regarding biblical exposition to the certainty of knowledge in his own natural philosophical endeavours:

> *Mallem quidem* (says he) *eorum que à me quæsivisti, habere scientiam quam ignorantiam: sed quia id nondum potui, magis eligo cautam ignorantiam confiteri, quam falsam scientiam profiteri.*
>
> (I should certainly prefer to have knowledge than ignorance of the things you have asked me. But since I have not yet attained it, I choose rather to confess cautious ignorance than to profess false knowledge.) (I, 295)[16]

This humility is characteristic of Boyle's position on knowledge.

Boyle's nescience, his reticence in making too strong a claim for as yet uncertain knowledge, is related to his aversion to system building and his ideal of a thoroughly comprehensive base of observational and experimental data on which to found our

[16] Hunter and Davis's translation.

understanding of nature. He argues in the 'Proemial Essay' of *Certain Physiological Essays, Written at Distant Times, and on Several Occasions* (1661)[17] that if men were more concerned with advancing natural philosophy rather than their own reputations then they would do mankind a great service. They should:

> set themselves diligently and industriously to make Experiments and collect Observations, without being over-forward to establish Principles and Axioms, believing it uneasie to erect such Theories as are capable to explicate all the Phænomena of Nature, before they have been able to take notice of the tenth part of those Phænomena that are to be explicated. (II, 14)

He criticizes the overzealousness of systematizers, at the same time as offering a more humble model in his own nescient practice. In his preface to *Spring of the Air*, Boyle writes 'Of my being wont to speak rather doubtfully, or hesitantly, then resolvedly, concerning matters wherein I apprehend some difficulty', and paraphrases Aristotle's *Rhetoric*, asserting:

> That to seem to know all things certainly, and to speak positively of them, is a trick of bold and yong Fellows: Whereas those that are indeed intelligent and considerate, are wont to imploy more wary and diffident Expressions. (I, 144)

Boyle betrays a sense of responsibility over the relationship between rhetoric and epistemology, always striving to hold himself in reserve from bold statements of certainty.

J. J. MacIntosh argues that as Boyle believed the reasons of God's creation to be '*à priori* undiscoverable by us', he did not hold *a priori* speculation and global theories to be useful.[18] MacIntosh writes that Boyle believed, 'As far as the deep structure of the world goes, we should be content with plausible hypotheses, so long merely as they are

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[17] Hereafter *Certain Physiological Essays*.

[18] London, The Royal Society, Boyle Papers (hereafter BP), 9/60^{r}, quoted in J. J. MacIntosh, 'Robert Boyle's Epistemology: The Interaction between Scientific and Religious Knowledge', *International Studies in the Philosophy of Science,* 6 (1992), 91–121 (p. 112).

intelligible, i.e. mechanical.'[19] He observes that Boyle was 'quite happy to leave things *un*explained.'[20] MacIntosh's readings against system building are consistent with the idea of different levels of understanding from *Things above Reason* and the belief that the development of useful and real knowledge within our sphere of limits (i.e. the mechanical world) was not incongruent with acceptance of the idea that there is also knowledge beyond human reason. However I think it is also important to note that the notion of different levels of knowledge is not quite as static as MacIntosh perhaps implies. Rose-Mary Sargent, while agreeing that Boyle consciously avoided what he felt were 'premature theoretical speculations' believing that this sort of system building closed the door to future lines of enquiry, also suggests that:

> while Boyle was cautious in his acceptance of corpuscular explanations, many passages in his work indicate that he did not believe that they would remain hypothetical forever. The experimental philosophy, as a method of discovery, was clearly meant to disclose truths about the world's hidden processes.[21]

The aversion to system building is not because hypothesis is the only possibility for limited human knowledge. As Peter Anstey observes, Boyle's objection is not to systematization in and of itself, but to the erection of systems which lack an observational foundation and which are supposedly impervious to correction or error, pointing out that, while not a systematizer himself, Boyle did promote a form of systematization in his advocacy of the collaborative and cumulative construction of Baconian histories of natural knowledge.[22] As I have shown above, Boyle's nescience is an aspirational one. Sargent similarly points out that Boyle's famous attitude of scepticism is not actually that of a Sceptic but is proposed in the hope of improving human knowledge.[23] Boyle writes in *Experiments and Notes About the Producibleness*

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[19] MacIntosh, 'Robert Boyle's Epistemology', p. 112.

[20] J. J. MacIntosh, 'Perception and Imagination in Descartes, Boyle and Hooke', *Canadian Journal of Philosophy*, 18 (1983), 327–52 (p. 341).

[21] Rose-Mary Sargent, *The Diffident Naturalist: Robert Boyle and the Philosophy of Experiment* (Chicago: University of Chicago Press, 1995), pp. 206, 42.

[22] Peter R. Anstey, *The Philosophy of Robert Boyle* (London: Routledge, 2000), pp. 4–5.

[23] Sargent, *The Diffident Naturalist*, p. 29. For a description of Boyle's scepticism as a rhetorical mode rather than a philosophical doctrine, see Jan V. Golinski, 'Robert Boyle: Scepticism and Authority in

Of Chymicall Principles (1680), 'I propose doubts not only with *designe*, but with *hope*, of being at length freed from them by the attainment of undoubted truth; which I seek that I may find it' (IX, 27–28).[24]

In *Things above Reason*, Sophronius claims:

> though I am very willing to believe, as well as I both desire and hope it, that this inquisitive Age we live in, will produce discoveries that will explicate divers of the more hidden mysteries of Nature, yet I expect that these discoveries will chiefly concern those things, which either we are ignorant of for want of a competent History of Nature, or we mistake by reason of erroneous Prepossessions, or for want of freedom and attention in our speculations. But I have not the like expectations as to all Metaphysical difficulties, (if I may so call them) wherein neither matters of Fact, nor the *Hypothesis* of subordinate parts of Learning, are wont much to avail. (IX, 373)

Boyle offers hope for the human knowledge of nature, but at the same time acknowledges the complexity of the world and of the structure and truth status of limited human knowledge. As Michael Hunter astutely comments, the emphasis on the generation of 'matters of fact' in Boyle scholarship obscures the true sophistication of Boyle's thinking on these issues.[25] The epistemological concerns reflected in Boyle's experimental programme, which he used to address the 'want of a competent History of Nature', reveal him, as he writes in *Certain Physiological Essays*, to be content:

> to contribute ev'n in the least plausible Way to the Advancement of it [experimental learning], and had rather not only be an Underbuilder, but ev'n dig in the Quarries for Materials towards so useful a Structure as a solid body of Natural Philosophy, than not do something towards the Erection of it. (II, 20)

The increasingly popular metaphor of the *Underbuilder* fits Boyle's epistemological

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Seventeenth-Century Chemical Discourse', in *The Figural and the Literal: Problems of Language in the History of Science and Philosophy, 1630–1800*, ed. by Andrew Benjamin, G. N. Cantor, and J. R. R. Christie (Manchester: Manchester University Press, 1987), pp. 58–82 (p. 61).

[24] Appended to the second edition of *The Sceptical Chymist: or Chymico-Physical Doubts & Paradoxes*.

[25] *Robert Boyle Reconsidered*, ed. by Hunter, 'introduction', p. 10.

position well.[26] The sense of working within a preparatory stage for natural philosophical knowledge makes sense of Boyle's acknowledgement of the complexity of nature, his resistance to systematization at the level of cause, and the aspirational quality of his nescience.

In the rest of this chapter I consider visual and spatial aspects of Boyle's work and how they relate more widely to his epistemology. As with Hooke, I will consider three main themes. I start with the legibility of nature, examining Boyle's use of the metaphor of reading the book of nature as a means of understanding the significance of the visible appearance of nature in his epistemology. I then consider the relationship between the visible and invisible worlds, detailing Boyle's theory of the make up of the air and the acts of inference and demarcation that allow for its observation, and considering the role of thought in moving beyond the visible. In the final section on the presentation of data to Boyle's reader, I consider the use of illustrations and figurative language in describing air, the concept of virtual witnessing, and, briefly, Boyle's practice of aggregation and attempts at ordering information, in terms of the production of the physical, textual, and mental spaces in which natural philosophy could take place.

The Legibility of Nature

In this section I consider the metaphor of the book of nature and the correlation between visibility and understanding in Boyle's philosophy, with a view to understanding how the study of invisible substances like air fits in with this. Although Boyle makes use of the book of nature metaphor, I find that his position is actually more complex than an idea of meaning — and indeed the word of God — being visually encoded in nature. Like Hooke, Boyle urges empirical observation but also insists on a layer of rational and experienced interpretation between sensory information and meaning. He also embraces the experimental method, taking a step beyond pure empirical observation to a more constructed form of generating knowledge. Boyle repeatedly distinguishes between a

[26] On Boyle as an under-builder, see Rose-Mary Sargent, 'Learning from Experience: Boyle's Construction of an Experimental Philosophy', in *Robert Boyle Reconsidered*, ed. by Hunter, pp. 57–78 (p. 58), and Sargent, *The Diffident Naturalist*, p. 38. Sargent notes that the under-builder motif was growing in popularity, citing uses by Bacon, Galileo, and Locke. Sargent, *The Diffident Naturalist*, p. 38, n. 103.

childlike admiration of visible stimulus and the skilled and learned understanding of the specialist that goes beyond this. However he also acknowledges the contingency and relativity of this skill or this capacity for knowledge, and distinguishes between the mechanics of nature, which can be read, and the divine causes of nature, which cannot. He insists that the message conveyed by the book of nature is one that should inspire wonder, and that the purpose of it is not necessarily to reveal God's secrets, which are reserved for heaven. Boyle's resistance to the idea of nature as a symbolic language leaves far greater room for a more genuine appreciation of its complexity and a more honest assessment of the difficulty of the natural philosophical task — an honesty that is also felt in his nescience. This leads him to seek ways of being able to faithfully interpret nature and thus to the experimental method, the artificiality of the controlled and demarcated experimental setting allowing Boyle to move beyond the superficiality of merely seeing and interpreting by instinct, to a deeper understanding of nature.

The book of nature is a pervasive metaphor in Boyle's oeuvre. In *Usefulness, I*, Boyle asserts that, 'each Page in the great Volume of Nature is full of real Hieroglyphicks, where (by an inverted way of Expression) Things stand for Words, and their Qualities for Letters' (III, 232). Similarly in his manuscript writings, Boyle says that, 'there are certain Hints [...] which to discerning Eyes (as Plants do to Physitians by their Signatures reveale their Propertys;) discloze much of what they conceale.'[27] Both quotations suggest a visible language of things that can be read. More specifically, the ideas of *real Hieroglyphicks* and *signatures* are suggestive of Paracelsian theories about reading the invisible properties of nature in their outward appearances.[28]

Boyle proposes that not only do these inscriptions manifest the goodness of God in his provision of instruction to man (III, 232), they also communicate God's attributes and wisdom. He claims that attributes of God are 'visibly display'd in the Fabrick of the World', and that 'many of Gods Attributes are legible in his Creatures' (III, 220). He further claims that 'In some of these [creatures] the Wisdom of God is so conspicuous, and written in such large Characters, that it is legible even to a vulgar Reader' (III, 222).

[27] BP, 7/285^{r}, quoted in J. R. Jacob, *Robert Boyle and the English Revolution: A Study in Social and Intellectual Change* (New York: Burt Franklin, 1977), p. 101.

[28] On Paracelsus and the *ars signata*, see James J. Bono, *The Word of God and the Languages of Man: Interpreting Nature in Early Modern Science and Medicine* (Madison: University of Wisconsin Press, 1995), pp. 129–40.

Boyle cites Plato: '*the World is Gods Epistle, written to Mankinde*' (III, 233), and riffs on the psalmist's assertion that the heavens declare the glory of God (III, 232). Even more than displaying God's attributes, the language of nature is seen to bear a direct communicative trace from God. Boyle gives scriptural precedent for communication by 'things' in God's rainbow after the flood and likens this sort of communication to Augustine's description of the sacraments as '*Verbum visibile*' (III, 233).

However, there is also a more sceptical — perhaps more practical — thread running through Boyle's works, which suggests that any interpretation which accepts that Boyle believed in a real and legible language of nature is overly simplistic. There are two strands to this reticence: one is related to Boyle's insistence on nescience and the distinction between what man is and is not able to know and thus read in nature; the other strand is about more practical issues of how much we are able to comprehend of nature visibly. Towards the end of *Usefulness, I*, Boyle, in line with his beliefs about the limits of human reason, warns his addressee, Pyrophilus, to expect great satisfaction from the 'Contemplation of Nature' but not as much 'as you may entirely acquiess in' (III. 274), which can only be satisfied wholly by God. He writes:

> the Creatures being as well uncapable to afford us a compleat Felicity by our Intellectual Speculations of them, as by our sensual Fruitions of them; for though the knowledge of Nature be preferrable by odds to those other Idols we have mention'd, as inferior to it, yet we here attain that knowledge, but very imperfectly. (III, 274–75)

The knowledge obtained from the contemplation of nature is better than that from other sources, but still obtained 'very imperfectly'. It does not afford us a 'compleat Felicity'. Also, *Intellectual Speculations* and *sensual Fruitions* are presented as parallel but separate modes of knowing; the visual (and other sensual) cues do not necessarily equate to knowledge without a layer of interpretation. And yet, Boyle does not aim to discourage the contemplation of nature, only to ensure that Pyrophilus is not disappointed with the limited knowledge it yields. The true felicity of the knowledge of God is reserved for a later revelation: 'we seek for that on Earth, which is not to be found but in Heaven' (III, 275).

The purpose Boyle attributes to the language of nature fits his idea of the limited knowledge of mankind. Boyle claims that there are two types of message: the informing of man of God's being and attributes, and the instructing of man in his own duties. These messages are not framed in the context of understanding God, but of inspiring humility before him. Boyle presents the world as a 'School of Virtue' and the benefit to man in contemplating creatures as 'promoting his [man's] Piety' (III, 234). Boyle writes:

> though many of Gods Attributes are legible in his Creatures, yet those that are most conspicuous there, are his Power, his Wisdome, and his Goodnesse, in which the World, as well as the Bible, though in a differing, and in some points a darker way, is designed to instruct us. (III, 220)

The attributes of God that man may read in creation are his greatness, not his reason or his methods. This suggests that the contemplation of nature is more to promote a level of knowledge of creation that inspires wonder and worship, rather than to achieve a true understanding of God and his ways. The idea of the language of nature being 'in some points a darker way' than the Bible also suggests that knowledge derived from the observation of nature will not be absolute, nor as easy to interpret. Emphasis is placed on the difference between the two types (literal and metaphorical) of reading. In a similar manner to the idea of God's communications inspiring wonder, Boyle (citing Psalms) asserts that one of the ways by which God communicates his power is the fact that '*his greatness is unsearchable*' (III, 221). Nescience points to God. Boyle comes to this conclusion by considering both the vastness of the firmament using even the most modest computations, and also the technical difficulty encountered by natural philosophers in measuring and calculating celestial distances (ibid.). Both the advances and limits of science point to the greatness of God, but not necessarily to his methods.

Boyle separates the idea of mechanical knowledge of the creation from knowledge of the reasons and methods of God by pointing out man's inability to mimic God in the act of creation: 'as highly as some Naturalists are pleased to value their own knowledge, it can at best attain but to understand and applaud, not emulate the Productions of God' (III, 222). In an adaptation of the image of Descartes's clockwork universe, Boyle compares this relationship to that of a novice admiring the skill of a watchmaker. Boyle extends this idea in a meditation on physiology:

> an Anatomist, though when by many and dexterous Dissections of

> humane Bodies, and by the help of Mechanical Principles and Rules [...] he has learn'd the Structure, Use and Harmony of the parts of the Body, he is able to discern that matchless Engine to be admirably contriv'd, in order to the exercise of all the Motions and Functions whereto it was design'd: And yet [...] could never have imagin'd or devis'd [such] an Engine. (Ibid.)

Boyle acknowledges the high level of learning and knowledge the anatomist possesses, but also the shortfall between the anatomist's knowledge and that of the Creator of the human body. Understanding at a mechanical level is not the same as being able to imagine or devise the creation of a being. And yet, limited as it is, mechanical knowledge is still presented as a relatively esteemed and valuable knowledge.

This sense of distinction between what is knowable and unknowable, and the idea of relative value is also found in Boyle's use of the theological trope of the *via negativa*. In *Some Motives and Incentives To the Love of God. Pathetically Discours'd of, in a Letter to a Friend* (1659)[29] Boyle meditates on the inadequacy of language for describing God:

> our Words being but the Representations of our Notions, and they being necessarily Finite, as our Being; few men are (me-thinks) more likely to be mistaken in the Nature of what's Infinite, (and consequently of Gods Attributes) than those that think Descriptions can comprize it. (I, 90)

The disproportion between finite representations and infinite natures makes human language inadequate to the task. Boyle thinks 'Silence the properest Language' (ibid.) when speaking of God's perfections, 'for 'tis Silence that best expresses our wonder [...]; A prostrate Veneration being the safest Apprehension of Him, that is Incomprehensible' (I, 90–91). Boyle, in his description of the sorts of expressions that would be hyperbole when applied to anything other than God, writes that even these superlative expressions, 'do but express our Devotion, not the Divine Object of it, and declare How much we honour Him, rather than What He is' (I, 137–38).[30] In so doing,

[29] Written in 1648. Hereafter *Seraphic Love*.

[30] This quotation is taken from 'An Occasional Reflection upon a Letter, (Receiv'd in *April*, 1662.)', which was added to the third edition of *Seraphic Love*, published in 1663.

Boyle makes a subtle distinction between man's understanding and objective truth and also emphasizes the relativity of both value and comprehension.

At the same time as emphasizing the inadequacy of human language to understand or express God, Boyle continues to use the metaphor of literacy to describe the knowledge of creation available to mankind. In a complex exploration of comparative knowledge across the hierarchy of beings, Boyle ponders the difference between the 'Clear and Radiant Light', 'Nearer Access', and 'more Illuminated Intellects' of angels, and 'the dim Twi-light of Human Intellects in this Life' (III. 136–37). Again deferring to the image of the anatomist, Boyle uses a comparison between a natural philosopher and an illiterate man as an analogy for the contrast between angels and men:

> how much more Advantageous Conceptions of the Wisdom displayed in the Universe, and particularly in the Contrivance of a Human Body, one that is a true Philosopher, and a skilful Anatomist may have, in comparison of a man illiterate, and unacquainted with Dissections. (I, 136)

In this network of relations, literacy has relative value. Compared to angelic or divine knowledge, even educated men are like the illiterate man to the philosopher, the illiteracy of mankind echoing the inadequacy of even hyperbolic language discussed just a few lines before. And yet, the anatomist is still figured as having a more advantageous conception of the wisdom of the universe compared to the illiterate man unacquainted with dissections. Again the metaphorical nature of literacy is highlighted by the contrast between illiteracy and the ability to 'read' anatomy and dissections, rather than the ability to read text.

I now turn to the second strand of resistance to a direct and simple interpretation of the metaphor of the language of nature: the practical difficulty in reading it. In discussing the potential for new discoveries in nature in *Usefulness, I*, Boyle describes the virtues hidden in, 'even those which daily obtrude themselves upon our careless Eyes, or are trampled under our regardlesse Feet' (III, 231), suggesting that the way man sees nature does not in fact easily comprehend visible signatures, as the Paracelsians suggest. Boyle also compares the pleasure of understanding the 'admirable Architecture and skilfull contrivance' of nature to that of simply seeing it visibly:

> For the Book of Nature is to an ordinary Gazer, and a Naturalist, like a rare Book of Hieroglyphicks to a Child, and a Philosopher: the one is sufficiently pleas'd with the Odnesse and Variety of the Curious Pictures that adorne it; whereas the other is not only delighted with those outward objects that gratifie his sense, but receives a much higher satisfaction in admiring the knowledg of the Author, and in finding out and inriching himselfe with those abstruse and varied Truths dexterously hinted in them. (III, 200–01)

There is a layer of skill, knowledge, and interpretation required in order to be able to properly appreciate and understand (to some degree) the book of nature. Merely seeing is not enough. The index to the work offers the following description for this portion of the text: '*That the knowledg of the inward Architecture and contrivances of Nature is more delightfull then the sight of the outward shapes*' (III, 286). It mentions nothing of signatures or the language of nature, and in fact contrasts the inner knowledge of nature with its outward shape instead of considering them to be causally related. This suggests that the simile of hieroglyphics is merely a figurative illustration rather than a substantive description of a model of epistemology. It also uses comparison to highlight the relativity of insight and knowledge.

In *Usefulness, I*, Boyle explores a related metaphor of atoms as letters. He expresses his scepticism for the Epicurean notion that creation occurred by chance, by means of a comparison to an accident in a printing house:

> And really it is much more unlikely, that so many admirable Creatures that constitute this one exquisite and stupendous Fabrick of the World should be made by the casual confluence of falling Atoms, justling or knocking one another in the immense vacuity, then that in a Printers Working house a multitude of small Letters, being thrown upon the Ground, should fall dispos'd into such an order, as clearly to exhibit the History of the Creation of the World, describ'd in the 3 or 4 first Chapters of *Genesis.* (III, 253)

Boyle uses the popular Epicurean analogy between atoms and letters, in conjunction with the unlikely idea of chance disposing of the fallen letters into their biblically ascribed places, to imply the necessity of an author to order the letters meaningfully.[31] Although Boyle rejects Epicurean chance causality, the analogy between atoms and letters suggests a relationship between the idea of a language of nature and the idea that corpuscular arrangement is significant to the properties of a body. However, corpuscular arrangement is of course not visible, even to the assisted eye, so this would be a language requiring a more complex means of interpretation than mere sight.

Richard Kroll describes the analogy between atoms and letters as being ‘arguably Robert Boyle’s most pervasive simile’.[32] However, it does not appear in any of the experimental writings consulted for this study, perhaps suggesting that while the *idea* of the language of nature is used as a metaphor for natural philosophy, it does not play any part in its experimental or interpretative practices in any literal sense — that is, the idea of an inscribed code is not an epistemological model. In *Spring of the Air* there is a reference to letters written in the dust at the top of Mount Olympus that over the passage of time have not been disturbed by the winds, but despite the metaphoric potential of this image, Boyle considers it only as an observed phenomenon offering evidence about the presence and behaviour of air up a mountain (I, 285). The only other occurrences of letters found throughout the experimental works, are when they are used to label illustrations or to denote wind direction in weather tables, uses which are self-consciously arbitrary.

When Boyle considers the mechanics of language use, particularly in the context of natural philosophy, he expresses a view of language as contingent. In *An Account of Philaretus during his Minority* (an autobiographical account written in 1648 or 1649), Boyle describes his younger self: ‘for he was so addicted to more reall[33] Parts of Knowledge, that he hated the study of Bare words, naturally; as something that relish’t too much of Pedantry’.[34] Boyle distinguishes between *reall* or *solid* knowledge and

[31] For the simile used by the ancient atomists, see Lüthy, ‘The Invention of Atomist Iconography’, p. 131. Boyle also uses Aquinas’s image of a philosopher writing with a pen as an analogy for the necessity of the guidance of an intelligent agent of creation (III, 259), see Timothy Shanahan, ‘God and Nature in the Thought of Robert Boyle’, *Journal of the History of Philosophy*, 26 (1988), 547–69 (pp. 561–64).

[32] Richard W. F. Kroll, *The Material World: Literate Culture in the Restoration and Early Eighteenth Century* (Baltimore: Johns Hopkins University Press, 1991), pp. 106–07.

[33] ‘Solid’ is given as an alternative to ‘reall’ above the line.

[34] Robert Boyle, *Robert Boyle by Himself and his Friends*, ed. with introduction by Michael Hunter (London: William Pickering, 1994), p. 10.

Bare words, emphasizing the rootedness of his study in things rather than texts. The older Boyle urges language reform as a part of the new philosophy, expressing frustration with the language of the chemists who use multiple names for the same thing and the same name for different things.[35] These ideas suggest a view of language as arbitrary and conventional rather than inherently meaningful, which distances Boyle from the literal idea of a symbolic language of nature. As he writes in *The Origine of Formes and Qualities, (According to the Corpuscular Philosophy)* (1666–1667), Boyle believes it more appropriate 'to alter Words, that they may better fit the Nature of Things', than to try to yoke the understanding of nature to words, 'that were probably devis'd, when the things themselves were not known or well understood, if at all thought on' (V, 344).

James Bono argues that in the seventeenth century, in contrast with those, like the Paracelsians, who embraced an exegetical or emblematic approach to nature, there were also philosophers who believed in the estrangement of man from the pre-lapsarian understanding of the word of God. Bono writes:

> Some students of nature refused to read the Book of Nature as a text written in symbolic, veiled language mirroring the Word of God [...]. Rather, they began to read nature as a text in which God had inscribed, not His deepest mysteries, but merely His scheme for the order and functioning of created things.[36]

This results in a language of 'things' not of 'symbols', and a focus on 'works' rather than 'Word'.[37] As Bono describes, this approach relies on a divine author who has inscribed but distanced himself from his text, rather than one who has stamped a fragment of his own image upon things. This language of things:

> Characterizes the natural order as humans come to experience, manipulate, and know it. But it is always a *contingent* language bespeaking a *contingent* natural order wholly dependent upon God's will.[38]

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[35] Golinski, p. 64.

[36] Bono, p. 83.

[37] Ibid.

[38] Ibid.

This contingent, inscribed, distant language of things expressing an internal order and scheme fits well with Boyle's presentation of the language of nature trope. Similarly, the experimental mode captures well Bono's notion that the contingent language of things 'characterizes the natural order as humans come to experience, manipulate, and know it'.

As well as the rainbow after the flood, the other examples Boyle gives for the precedent of God's communication through 'things' are Solomon's stricture to the sluggard to learn from the ant, and Christ's instruction to his disciples to learn prudence and inoffensiveness from serpents and pigeons. This sort of 'reading', based in observational learning, is much more Baconian. It is less about the decoding of symbols or signatures and more about observing the scheme of order present in creation on its own terms (much like Hooke's networks of relations which resist the temptation to read the known macro world into the unknown micro one). When Boyle describes the wisdom of God as conspicuous and written in 'such large Characters, that it is legible even to a vulgar Reader' (III, 222), he continues with the following caveat: 'But in many others the Lineaments and Traces of it are so delicate and slender, or so wrapt up and cover'd with Corporeity, that it requires an attentive and intelligent Peruser' (ibid.). As with the consideration of the behaviour of ants, serpents, and pigeons, the requirement for an *intelligent peruser* as well as an *attentive* one suggests the need for a more interpretive and inferential approach to the language of nature than the simple and direct reading of visible signs. It is a call for natural philosophy.

The idea of a language where words perfectly express things is often associated with man's dominance over other creatures, as related in Genesis at Adam's naming of the animals. However, when discussing how God's goodness is apparent by his provision for man's needs, Boyle describes:

> God's liberality at once bestowing on him all those Creatures by endowing him with a Reason enabling him to make use of them; so that even those Creatures which he is not able to subdue by his Power, he is able to make serviceable to him by his Knowledg. (III, 229)

In Boyle's interpretation of God's bestowal of dominion over creatures, man's relation to and power over other creatures is dependent on his reason, his ability to figure out how best to utilize their properties, not on his command of language and knowledge of their true names. In fact, the dependence indicated by *so that*, suggests that for Boyle this sort of reason *is* man's knowledge.

Sargent observes that because of the complexity of the book of nature, our understanding, 'will depend upon knowledge of a vast number of particulars and upon our ability to reason correctly about the relations that hold between them.' She emphasizes the need for a method of proof which has the 'flexibility exhibited by moral demonstration' in order to assure the progression of knowledge and its revision and refinement as it is increased. She holds that for Boyle, it was the experimental method that accommodated these needs and offered a means of interpreting the book of nature.[39] Sargent elsewhere asserts that experiments provide Boyle with a way to avoid what he describes as 'the superficial account given us of things by their obvious Appearances and Qualities' (III, 204).[40] The passage in *Usefulness, I* from which this quotation is taken also speaks of the importance of going further than the 'unurg'd [...] slight, reflections on the Information of the Senses' that creatures possessing reason make by instinct (ibid.). Boyle urges that these impressions be not only received by means of our nature, but improved on by means of our industry, if we are not to settle for the said superficial account. As Sargent argues, 'As the level of artificiality in an experiment increases, the level of superficiality decreases.'[41] Like the demarcated space of the printing house in the thought experiment against chance creation, the artificiality of experiment allows for the containment, control, and measurement of variables so that facts and (mechanical) causes can be isolated. It also allows for the investigation of properties and information that are not immediately obvious to the senses.

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[39] Sargent, *The Diffident Naturalist*, pp. 111–12. Note that this relies on understanding experimental philosophy as a method of interpretation rather than just observation, which is one of the key contributions of Sargent's work to Boyle scholarship.

[40] Sargent, 'Learning from Experience', p. 68.

[41] Ibid.

Visible and Invisible Worlds

In this section, I consider the relationship between the visible and invisible worlds in Boyle's thought on the nature of air. I consider how the air is conceived of by Boyle; the acts of inference which allow the observation and collection of data on this invisible substance; the role of instruments, both in practical experimentation and as a way of thinking about the mechanics of bodies beyond sight and the mechanics of thinking itself; the concept of corpuscularian structure; and the roles of wonder, imagination, and metaphor in thinking and working beyond the visible.

The ridicule and satire the new philosophers faced for their investigations into the nature of air rely on its invisibility being equated with immateriality and thus inconsequentiality. Pepys's diary entry for 1 February 1664 recounts Charles II laughing at the members of Gresham College, 'for spending time only in weighing of ayre, and doing nothing else since they sat.'[42] Similarly in Shadwell's *The Virtuoso* (1676), Gimcrack cuts a ludicrous figure with his collection of country airs and his out-of-water swimming lesson, the spectacle of invisibility on the stage reducing the value of his investigations to nothing. Gimcrack's descriptions of air send up the ideas of Boyle and Hooke as the fantastical ravings of an over-inflated buffoon who is out of touch with common-sense reality:

> The whole air is full of living creatures a thousand times less visible than those living creatures mistaken for motes in the sun. I know most of 'em distinctly by my glasses.[43]

These lines conflate microscopical natural history with corpuscularian philosophy, the comparison to motes in the sun being a reference to Lucretius's famous analogy for atoms in the air in *De Rerum Natura.* As well as the confusion of ideas, the extreme levels of instrumental vision bragged of by Gimcrack undermine his claims. After describing his microscopical investigations, Gimcrack tells his sceptical audience,

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[42] *The Diary of Samuel Pepys*, ed. by Robert Latham and William Matthews, 11 vols (London: Bell & Hyman, 1970–83), V (1971), 33.

[43] Thomas Shadwell, *The Virtuoso*, ed. by Marjorie Hope Nicolson and David Stuart Rodes, (Lincoln and London: University of Nebraska Press, 1966), IV. 3. 214–17.

Bruce and Longvil, of his vault full of country air: 'I employ men all over England, factors for air, who bottle up air and weigh it in all places, sealing the bottles hermetically.'[44] As Anstey points out, Gimcrack's brag of a consignment of air from the peak of Tenerife is possibly a direct reference to Boyle, who describes weighing air from Tenerife in *Tracts Written by the Honourable Robert Boyle Containing New Experiments, touching the Relation betwixt Flame and Air* (1672).[45] The superlative extent of the operation, 'They send me loads [...]. That vault is full',[46] emphasizes its disproportionate lack of utility in the amount of space taken up by the collection. Indeed it is a collection that has only the most self-indulgent of uses:

> Now if I have a mind to take country air, I send for maybe forty gallons of Bury air, shut all my windows and doors close, and let it fly in my chamber.[47]

As well as belittling the purpose of the natural philosophical programme, Gimcrack's practice of letting the air fly about his chamber undermines the idea of carefully demarcated experimental spaces, ridiculing the efforts of practitioners like Boyle to assure their integrity. These satirical presentations rely on taking the concept of invisible and subvisible matter out of the context of strict experimental environments in which philosophers can perceive such phenomena, and into a realm whose epistemology operates at a macro level and relies on a close relationship between visibility and reality (emphasized by the romantic farce of disguise, mistaken identity, and dark and secret rooms in Shadwell's play). This associates invisibility with nothingness, and the idea that the invisible air could be teeming with subvisible bodies (creatures or atoms) is dismissed as ludicrous. Longvil's question 'To what purpose do you weigh air?' is left unanswered.[48] Gimcrack's practices are deemed to have no valuable purpose.

In *General History of Air*, Boyle acknowledges this common way of thinking

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[44] Shadwell, *The Virtuoso*, IV. 3. 256–58.

[45] Peter Anstey, 'Literary Responses to Robert Boyle's Natural Philosophy', in *Science, Literature and Rhetoric in Early Modern England*, ed. by Juliet Cummins and David Burchell (Aldershot: Ashgate, 2007), pp. 145–62 (p. 146). Cf. *The Virtuoso*, IV. 3. 261.

[46] Shadwell, *The Virtuoso*, IV. 3. 258–59.

[47] Ibid., IV. 3. 264–66.

[48] Ibid., IV. 3. 268.

about the air:

> the Generality of Men are so accustomed to judg of things by their Senses, that not finding the Air to be a visible Body, they ascribe less to it than even the School-men do; and what is invisible, they think to be next Degree to nothing. (XII, 132).

Such men consider the Air, 'only as a Receptacle' (ibid.) and do not show any awareness of actions of the air on bodies harboured within it, beyond perhaps heat and moisture. But Boyle sees the air differently. As outlined in the introduction to this chapter, he believes it to be populated with or comprised of particulate bodies, and turns it from a receptacle into an object in its own right. He acknowledges the difference in his way of looking, 'But for my part, who look upon the Air under another Notion' (ibid.), and describes his opinion that the air may alter as well as contain bodies — an idea which has a sense of thingness, of mechanical activity and potency. In Boyle's work, while he acknowledges the air's invisible and ethereal qualities, air is never treated as nothing, but always as a real and material presence. The overall effect of this zooming in and considering substantiality at such a micro level is one of denseness.

General History of Air opens with a definition of '*What we understand by the* AIR':

> By the *Air* I commonly understand that thin, fluid, diaphanous, compressible and dilatable Body in which we breath, and wherein we move, which envelops the Earth on all sides to a great height above the highest Mountains; but yet is so different from the *Æther* [or *Vacuum*] in the intermundane or interplanetary Spaces, that it refracts the Rays of the Moon and other remoter Luminaries. (XII, 12)[49]

The air is thin and diaphanous, but it is contrasted with aether or vacuum, and the inclusion of the adjectives *compressible* and *dilatable* give the air a real sense of resistance and weight by triggering a mental image of the acts of compression and dilation. The idea of enveloping creates an exaggerated sense of its substantiality which helps redefine how we think of the air 'in which we breath, and wherein we move', activities whose effect is to draw attention to that presence and ubiquity which is taken

[49] The square brackets are Boyle's.

for granted.

Boyle continues to Title II, '*Of the constant and permanent* Ingredients *of the Air*', in which he lists three kinds of corpuscles which make up what he calls the atmospherical air or 'the common Air we breath and move in' (ibid.) — as opposed to the purely elemental, ethereal, or celestial substances supposed by other philosophers. These three kinds are: vapours or exhalations from earth, water, minerals, creatures etc.; '*Magnetical* Steams' (XII, 13) and the subtle material particles that allow the transmission of light; and the '*Perennial* Air' (XII, 14), that is, particles that are permanently air. These perennial air particles are the ones that are elastical. Boyle details four different analogies for this quality (springs of watches, hairs of wool, slender wires, shavings of wood) and acknowledges that other comparisons can also be made. The densely detailed descriptions, combined with the listing of multiple types of particle and multiple analogies for their qualities, have the effect of densely populating the invisible air with these ideas and images, and creating a sense of intricacy in how we think about the air.

In *Things above Reason*, Boyle clearly outlines the difficulty in knowing of invisibles:

> To our confused, and often also to our inadequate conceptions, belong many of those that may be called Negative, which we are wont to imploy when we speak of Privations or Negations, as Blindness, Ignorance, Death, *&c*. We have a positive *Idea* of things that are square and round, and black and white, and in short of other things, whose shapes and colours make them the objects of our sight: But when we say, for instance, that a Spirit or an Atome is invisible, those words are attended with a negative conception, which is commonly but dark and confused because 'tis indefinite, and removes or lays aside those marks, by which we are wont clearly to perceive and distinguish visible substances. (IX, 385)

As with his apophatic descriptions of God in *Seraphic Love*, Boyle distinguishes between visible things that allow us a positive idea of them, and invisible things that only allow us a negative conception. Although Boyle treats atoms as material, and creates tangible mental images for them (such as the analogies for the elastical qualities of air), he here refers to them as invisible, listing them in the same breath as immaterial spirits. This does not seem to be a dilemma of observation that will be solved with more powerful microscopes. Boyle shortly after continues:

> of some things we have a knowledge, that for want of a fitter term may be called primary or direct, and of some other things the knowledge we have is acquired but by inferring it from some more known or clearer truth; and so may be called inferr'd or illative knowledge. (Ibid.)

The way Boyle finds for obtaining knowledge of invisibles is by inference from what is 'more known or clearer'. One of the benefits of investigating nature by means of experiments is the ability to control the environment and its variables, and to limit the unknowns, to make this process of inference more systematic and reliable.

Even for Boyle who 'sees' the air differently to the generality of men who see invisibles as the next degree to nothing, it is the relationship of air to other bodies that allows it to become perceivable. In *General History of Air*, Boyle writes: 'I am apt to allow it [air] *in reference to some Bodies*, certain other Faculties and Powers' (XII, 132, my emphasis). There are numerous examples in Boyle's works detailing experiments and their interpretation of the perception of the behaviour of air by means of its interactions with other visibly observable bodies, such as inflated bladders and extinguished flames. In the indexical summary of *Spring of the Air*, the second experiment is described as 'touching the pressure of the Air against the sides of the Bodies it invirons' (I, 150). The air is demarcated in negative by the positive boundary of visible objects. Boyle also uses the perception of the other senses, for example, on the turning of the key to allow air into the receiver he notes, 'there is immediately produced a considerably brisk noise' (I, 165), and in *A Continuation of New Experiments Physico-Mechanical, Touching the Spring and Weight of the Air, and their Effect. The Second Part* (1682),[50] which comprises a large number of experiments on the rotting of food items, the effects of air and vacuum are inferred from observations on the change of appearance, taste, and smell.

An important condition for making inference is the ability to control and know the experimental space. This is predominantly achieved by the knowledgeable use and description of instruments. In the first experiment, Boyle gives the following explanation of the pumping out of the air from the receiver to the cylinder and out of the

[50] Hereafter *Spring, 2nd Continuation*.

apparatus:

> This you will easily perceive, by finding, that you still force less and less Air out of the Cylinder; so that when the Receiver is almost exhausted, you may force up the Sucker almost to the top of the Cylinder, before you will need to unstop the Valve to let out any Air: And if at such time, the Valve being shut, you let go the handle of the Pump, you will finde the Sucker forcibly carryed up to the top of the Cylinder, by the protrusion of the external Air; which, being much less rarified then that within the Cylinder, must have a more forcible pressure upon the Sucker, then the internal is able to resist: And by this means you may know how far you have emptyed the Receiver. (I, 164–65)

Boyle is addressing himself to the possible ambiguity as to whether the receiver is full or empty of air. By means of a detailed instruction in the use of the air pump and the way in which the equipment behaves through the different stages of the process he allows the reader to understand how the experimental space — and thus the objectified air or vacuum — is demarcated, and how the air is moved through it.

In the seventeenth experiment of *Spring, 1st Continuation*, Boyle details a device he has invented to measure the rarity of the air in the receiver to further abate this problem:

> Because the Air being invisible, it is not always easie to know whether it be sufficiently pump'd out of the Receiver that was to be exhausted; we thought it would be very convenient to have some Instrument within the Receiver, that might serve for a Gage, or Standard; whereby to judge whether or no it were sufficiently exhausted. (VI, 78)

He lists various considerations and then offers detailed making instructions for the gauge, which can calculate specific volumes of air, either by calculation or by empirical comparison with water volumes. As with the description of using the air pump, this detailing of instrumental technology helps the reader mentally trace the movement of air, as well as providing the practitioner with a means for visually observing changes in pressure.

The use of inference to make invisibles perceptible to the senses is not all Boyle relies on though. As Sargent details, Boyle's experimental method relies on a notion of experience that is more than just simple sense perception.[51] Sargent demonstrates that, like a jury trying to discover and justify the facts of a case from the evidence presented before them, Boyle's method relies on standards of rational assent, and demonstration on a balance of probabilities.[52] As Boyle describes in *Usefulness, I*, William Harvey makes inferences from the valves in the heart about the circulatory function of the whole system, which are then subsequently proven by experiment (III, 222).[53] Like Harvey, Boyle uses a mixture of observation and reason for making inferences about unobservable phenomena. Sargent explains that this use of teleological reasoning is not inconsistent with the rejection of appeals to final causes, and that as long as such conjectures are tested and proven by experiment, 'then they have a positive heuristic role and can indeed be seen as necessary adjuncts to the mechanical philosophy'.[54] This dynamic allows for a progressive and self-refining model of knowledge in which reason and observation influence and test each other to produce knowledge that is reliable in its probability.

This method is useful in the case of invisibles, but can also have the effect of co-opting the conditions of observation to phenomena itself, for example when Boyle suggests that being able to see further in different conditions is because of changes in the density of the air (I, 204). This is not unreasonable, but it does highlight a tendency to circularity inherent in this mode of thinking and explanation. There are also instances in Boyle's work where the phenomena from which hypotheses of invisibles is inferred is itself assumed or implied by figurative language rather than plainly reported. For example in *Spring of the Air*, Boyle describes:

> For that still there remain'd in the capacity of the exhausted Cylinder store of little rooms, or spaces empty or devoid of Air, may appear by the great violence wherewith the air rushes in, if any way be open'd to it. (I, 244)

That the air has rushed in we as readers assume to have been evident by means of sound

[51] Sargent, *The Diffident Naturalist*, p. 50.

[52] Sargent, *The Diffident Naturalist*, p. 54.

[53] See also Sargent, *The Diffident Naturalist*, p. 80.

[54] Sargent, *The Diffident Naturalist*, p. 81.

or felt movement of the air, implied by the character which *violence* and *rushes* give the presumed movement. Another instance of the ambiguous or organic gauging of conditions is found in *Spring, 1st Continuation*, where Boyle defers to the experience of experimenters to assure the emptiness of the pump, ignoring the instrumental gauge and bypassing the usual anxiously detailed explanation of exsuction, merely writing: ‘it was easy for them that are well acquainted with the Pump, to estimate what Air is left in the vessel it should exhaust’ (VI, 75). On one level the deferral to familiarity is reasonable and practical, and the likelihood of an experienced practitioner being able to correctly match similar states is high, but in not using some external means of measurement it is circular in that it relies on the assumption that the previous experiences mean what we have always assumed them to mean. These examples demonstrate an imbrication between experience, reason, and inference, which is more complex than simple empirical observation.

Much has been made of the idea that Boyle separates his descriptions of experiments from his more speculative discussion of their significance; an interpretation which is based on the fact that he tells us that he does this in his preface to *Spring of the Air*. His intention is that readers, ‘who desire onely the Historical part of the account we give of our Engine, may read the Narratives, without being put to the trouble of reading the Reflections too’ (I, 144). However in practice, Boyle does not always keep the two cleanly separated. Nor does his explanation include anything about keeping narrative and reflection separate for epistemological reasons; this is something that has been read into the text by subsequent critics, and assumed to be part of Boyle’s nescient approach.[55] In the first experiment of *Spring of the Air*, Boyle writes:

> For the more easie understanding of the Experiments tryable by our Engine, I thought it not superfluous, nor unseasonable in the recital of this first of them, to insinuate that notion by which it seems likely that most, if not all, of them will prove explicable. (I, 165)

As a means of making the experiments understandable, Boyle offers his hypothesis of their cause. As such, his readers share in the teleological approach described by Sargent above, reading the experiments through Boyle’s hypothesis of the spring of the air. Boyle does also describe the Cartesian hypothesis and assures the reader that while both

[55] See for example, Golinski, p. 387.

accounts are plausible accounts, neither ‘gives us a sufficient account of its Nature’ (I, 167), but the experiments are framed and discussed through the lens of his own hypothesis. In fact, while there is a general distinction between passages that are mostly narrative and those that are mostly reflection, it is not uncommon for reflections and speculations to crop up within the narrative reports. For example, in Experiment 10 of *Spring of the Air*, Boyle writes:

> We took notice that when the Air was not drawn out, there did upon the extinction of the Flame a considerable part of the Week remain kindled, which (probably by reason of the Circulation of the Air in the Vessel, occasion’d by the heat) emitted a Steam. (I, 185)

Although demarcated by a parenthesis, a speculative reason for the phenomenon is offered in the midst of the narrative account.

That theory and hypothesis contribute to the development of experiment can be seen in the description of the air pump in *Spring, 1st Continuation*, where Boyle describes his addition of a plate of iron:

> which I added, not onely to keep the wooden Board the better from warping, but because I knew (what will perhaps be thought strange) that the pressure of the Atmosphere on one side of the Board, when there is no pressure or but very litle on the other side, will enable many Aerial particles to strain through the very wood. (VI, 37)

This is asserted as certain, ‘I know’, and yet it still has the feel of a hypothetical explanation for the unobservable and unattributable phenomenon of the receiver not being airtight. This theory has influenced the experiment to the point of suggesting alteration to the instrument.

When Boyle describes the bystander trying to remove the key or stopple from the exhausted receiver in Experiment 2 of *Spring of the Air*, he acknowledges the role of assumption in the bystander’s understanding of what is happening:

> men being unus’d to finde any resistance, in lifting things up, from the free Air above them, they are forward to conclude that that which depresses their hands must needs be some weight, though they know not where plac’d, drawing beneath it. (I, 171)

These men make a conclusion about *weight* due to their different theoretical preconceptions. For Boyle this appears to be an example of the superiority of thought and understanding of experimental philosophers — indeed Boyle is able to back up his explanation of the phenomenon with the further test of what happens when the air is returned to the receiver — but it also exemplifies the influence of any theoretical assumptions and the dangers, albeit on a more subtle scale, that Boyle himself faces in his own inferential thinking.

The major hypothesis about invisibles underlying Boyle's work is his corpuscularianism, which, while material, is a structure operating at a sub-microscopic level and effectively invisible. As Margaret Osler describes, Boyle leaves aside the metaphysical question of whether indivisible, Epicurean atoms exist and describes the microscopic structure of the material world in terms of *minima naturalia*, tiny particles below the threshold of sense, which, while divisible in principle, are hardly ever divided.[56] Norma E. Emerton shows that Boyle makes inferences about atomic structure from the structural organization of matter at a macro level. Like the fallen letters in the printer's working house, order is deemed necessary. Boyle questioned the scholastic notion of substantial form and the chemists' salt principle as causes of crystallization, but felt that the specificity and constancy of the microscopic shapes found in crystals could not be the result of chance and inferred that the internal construction of crystals must also be geometrically regular, an idea supported by experiments which grew different shapes of crystals from different combinations of ingredients.[57] This is different to the Aristotelian dismissal of atoms as a rude heap, or even ancient atomism itself, which does not define the shapes of its particles.[58]

This thinking is likely connected to microscopy which, in allowing access to the subvisible world, provides an analogy for, and hence a way of visually imagining, the submicroscopic world. In Boyle's microscopic observations on cheese mites he writes

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[56] Margaret J. Osler, 'The Intellectual Sources of Robert Boyle's Philosophy of Nature: Gassendi's Voluntarism and Boyle's Physico-Theological Project', in *Philosophy, Science, and Religion in England 1640–1700*, ed. by Richard Kroll, Richard Ashcraft, and Perez Zugorin (Cambridge: Cambridge University Press, 1992), pp. 178–98 (pp. 183–84).

[57] Emerton, pp. 43–44.

[58] Lüthy, 'Atomist Iconography', pp. 118, 121.

that they 'seeme but [...] mouing Atome[s]'.[59] He further ponders how 'vnimaginably little' must the hairs upon the legs be in their turn, and the animal spirits travelling in the nerves within those legs, and the 'multitude of Atomes' making up the creature's several parts. Boyle's microscopic view of the cheese mite gives his mind a trigger to imagine the scale of even smaller parts. Similarly in his experiments on air, Boyle uses descriptions of macro level phenomena to suggest not only the presence of air, but its particulate nature. Boyle describes the mist arising from a waterfall as water having been broken 'into such minute Corpuscles' (I, 218), allowing *corpuscles* here to mean visible water particles rather than strict *minima naturalia*. There are also numerous descriptions of the production of bubbles in water, which, while describing much larger packets of air than atoms, offer a suggestive corpuscularian imagery in their multitude of small globules. Boyle describes the bursting of the receiver and a bladder:

> upon the quick depressing of the Sucker, the external Air burst the Body of the Viol into above a hundred pieces, many of them exceeding small, and that with such violence that we found a wide rent, besides many holes, made in the Bladder it self. (I, 182)

The resulting fragments of the body of the viol — above a hundred pieces, exceeding small — and the holes left in the bladder itself, are all suggestive of the particulate nature of the air that caused this, even though that itself cannot be pictured. Boyle suggests corpuscularity by the proximity of visible examples of fragmentation and particulate matter.

When Boyle describes the microscopical cheese mite, he also calls it a 'little Engine'.[60] The use of the machine or engine analogy is crucial to Boyle's understanding of invisibles, not just for its utility as a metaphor to help us conceptualize the workings of invisible or subvisible matter, but also for providing a basis for Boyle's assumptions of the consistency of the natural world, which underpin his hypotheses about the workings of non-perceivable objects. As Lorraine Daston and Katharine Park observe, Boyle's voluntaristic solution to the theological dilemma of the autonomy of nature is to

[59] BP, 26/169, quoted in J. J. MacIntosh, 'Robert Boyle on Epicurean Atheism and Atomism', in *Atoms, Pneuma, and Tranquility: Epicurean and Stoic Themes in European Thought*, ed. by Margaret J. Osler (Cambridge: Cambridge University Press, 1991), pp. 197–219 (p. 200).

[60] BP, 26/169, quoted in MacIntosh, 'Epicurean Atheism and Atomism', p. 200.

see nature as an 'artefact', not an 'artisan'; and indeed, an artefact of a specific nature, that of an 'engine' or 'automaton'.[61] Anstey explains that Boyle (and other natural philosophers contemporary to him) collapse the classical distinction between nature (physics) and mechanics by taking the step away from using the machine as an analogy to actually thinking of nature as a machine.[62] As with Hooke, the idea of the machine is an intimate part of Boyle's epistemology. Henry van Leeuwen argues that Boyle uses instruments to assist the senses but does not give the senses an autonomous role, quoting from the Boyle Papers: 'the Organs of Sense are but the Instruments of Reason in the Investigation of Truth'.[63] The human becomes machine and the machine becomes implicated in reason.

As well as portraying sensory function as machinic and imbricated with reason, Boyle also portrays the mental act of reason in a similar way. In the *Appendix* to *Christian Virtuoso*, Boyle writes, 'Philosophy does for the most part but more clearly display and expose the object' (XII, 424), the acts of displaying, exposing, and objectifying serving a similar function to the use of instruments and controlled conditions in the demarcating of experimental spaces. However, it is not just rational thought that Boyle refers to here. As Lotte Mulligan shows, Boyle used not only reason, but 'Right Reason' which she defines in relation to Boyle's thought as 'reason seasoned with revelation'.[64] Boyle continues:

> but divine revelation assisted by divine grace may serve both for a light, a telescope, and a collyrium; since it both illustrates the object, and furnishes the beholder with an excellent instrument of discovery, and clears the eye or visive faculty from those distempers, that render it unfit to exercise the best and difficultest acts of vision. (XII, 424)[65]

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[61] Lorraine Daston and Katharine Park, *Wonders and the Order of Nature, 1150–1750* (New York: Zone Books, 1998), p. 298.

[62] Anstey, *Philosophy of Robert Boyle*, p. 3.

[63] BP, 9/25, quoted in Henry G. van Leeuwen, *The Problem of Certainty in English Thought 1630–90* (The Hague: Martinus Nijhoff, 1963), p. 94.

[64] Lotte Mulligan, 'Robert Boyle, 'The Christian Virtuoso' and the Rhetoric of 'Reason'', in *Religion, Reason and Nature in Early Modern Europe*, ed. by R. Crocker (Dordrecht: Kluwer Academic, 2001), pp. 97–116 (p. 98).

[65] See also Mulligan, 'Robert Boyle, 'The Christian Virtuoso'', p. 110.

Not just philosophy, but revelation too functions as an instrument of discovery and an aid or salve for the senses. Boyle uses a similar instrumental analogy to describe the value of hermeneutic scholarship in the study of the Bible in *Some Considerations Touching the Style of the Holy Scriptures* (1661): ‘the Scripture being indeed like Heaven, where the better our Eyes and Telescopes are, the more Lights we discover’ (II, 431). Telescopes and eyes, those organs of sense, are used as metaphors for the tools needed to read the Bible. They are instruments of right reason and right reason is an instrument. As in *Things above Reason*, religious ideas are figured and explored alongside natural philosophical ideas and contexts. Here, *Heaven* is not figured as a religious location — the seat of God — but as the object of scientific study, the analogy being between understanding scripture and discovering stars with the aid of telescopes.

Instrumental metaphors are also used by Boyle for other acts of thought, including imagination and figurative description. In *Certain Physiological Essays*, Boyle describes the use of a florid writing style as akin to ‘paint[ing] the Eye-glasses of a Telescope’ (II, 16), and in the preface to *The Christian Virtuoso: Shewing, That by Being Addicted to Experimental Philosophy, a Man is Rather Assisted, than Indisposed, to be a Good Christian* (1690–1691),[66] he writes:

> proper Comparisons do the Imagination almost as much Service, as Microscopes do the Eye; for, *as* this Instrument gives us a distinct view of divers minute Things, which our naked Eyes cannot well discern; because these Glasses represent them far more large, than by the bare Eye we judge them; *so* a skilfully chosen, and well-applied, Comparison much helps the Imagination, by illustrating Things scarce discernible, so as to represent them by Things much more familiar and easy to be apprehended. (XI, 287–88)

Mulligan argues that for Boyle, similitude or metaphor is the key that reveals the secrets of nature.[67] I agree with her reading and add that there is an important epistemological commonality underlying sensory data, reason or philosophy, knowledge, revelation, imagination, and representation (i.e. ‘proper comparisons’) in the shared use of instrumental metaphors. They all become experimental tools for the investigation of nature. This explains the frequency of recourse to thought experiments and imaginative

[66] Hereafter *Christian Virtuoso, I.*

[67] Mulligan, ‘Robert Boyle, ‘The Christian Virtuoso’’, p. 111.

comparisons — which otherwise sits uncomfortably with an interpretation of Boyle as a pure empiricist — in his seemingly practical and experimental works.

As outlined in the introductory section to this chapter, Boyle, in his consideration of how man can know about things beyond his rational capabilities, makes a connection between invisibles and thoughts beyond our limits. In *Things above Reason*, Pyrocles questions knowing of the existence of things above reason 'as if we were told that we may see things with our eyes that are invisible' (IX, 371). Sophronius's response includes the line, 'we do not pretend that the Eye of the Mind should see Invisibles, but only that it shall discern the limits of that Sphere of Activity, within which Nature hath bounded it' (IX, 383). Sophronius's retort moves the question of visibles inside the mind so that it no longer becomes a question about literal, sensory seeing, but about metaphorical seeing or conceiving. Elsewhere in this work the notions of things being above reason and the inadequacy of our conceptions of such things is exemplified by examples of mathematical ideas too difficult for the mind to picture, such as the difference between the ideas of a myriagon and a chiliagon, or the infinite divisibility of a line (IX, 377–78). Sophronius also uses the atom as an example:

> So if you would imagine an Atome, of which perhaps ten thousand would scarce make up the bulk of one of the light particles of dust, that seem to play in the Sunbeams when they are shot into a darkned place, so extraordinary a littleness, not having fallen under any of our Senses, cannot truly be represented in our imagination. (IX, 377)

Boyle sets up an image rich in detail, stating the number of atoms to a dust particle and specifying the circumstances of the sunbeam to enable the reader to picture it. However, he then undermines the reality, and even possibility, of this, or any specific representation by closing with the idea that something so small cannot be truly represented in the imagination. There is a subtle move from a spatiality that is visual (even if imaginary) to one that is purely conceptual.

Boyle shies away from this sort of thinking when defining atoms more consciously, electing to use the idea of *minima naturalia*:

> The smallest particles of bodyes which they call Atomes not because they cannot be suppos'd to be divided into yet Smaller parts [...] but because tho they may be further divided by Imagination yet they

> cannot by Nature.[68]

Boyle elects for a more practical — and perhaps less controversial — definition here, but maintains a division between material and conceptual spatialities for the atom, perhaps even offering further levels of capability to the conceptual than he did in *Things above Reason* in the act of recursive mental division.

In Boyle's experimental works there is frequent invocation of what might, or indeed might not, be imagined. In *Spring of the Air*, Boyle describes the difficulty in keeping the pump tight to the external air: 'which when the Vessel begins to be exhausted, is much more difficult to be kept out then one would easily imagine' (I, 162), again framing his observation in negative to the mental picture conjured. Boyle also uses thought experiments as a means of testing the likelihood of things that cannot be practically tried, for example when considering how to weigh the air, he considers the impossible fantasy image: 'if we could lift a pair of Scales above the Atmosphere' (I, 254).[69]

As Sargent notes, Boyle 'rejected the empiricist equation of ideas with images in the mind'; he held that it is possible to form ideas about the existence of an object without having had a sense experience of it.[70] Although Boyle does use sensory data and visual imagery, he also accommodates other modes of conception, such as conception in negative relation to more concrete ideas. As seen in his use of the *via negativa*, the negative formulations have the ability to take man beyond the limit between the known and unknown, in some manner. Boyle connects this idea to the notion of visibility, which is so important for natural philosophical observations, in a way that accommodates the enrichment of experimental philosophy by what is not seen or what is beyond sight. In *Usefulness, I*, Boyle quotes from Augustine,

> *Non debes uti oculis* (says he) *ut pecus, tantum ut videas, quæ addas ventri, non menti: utere, ut homo, intende Cœlum, & intende Facta, & quære Factorem; aspice quæ vides, & quære quem non vides, crede*

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[68] BP, 26/162–63, quoted in Antonio Clericuzio, *Elements, Principles and Corpuscles: A Study of Atomism and Chemistry in the Seventeenth Century* (Dordrecht: Kluwer Academic, 2000), p. 117.

[69] On the similarity between this image and Milton's image of the scales of justice in Book IV of *Paradise Lost*, see M. S. Berkowitz, '"With Balanc't Air in Counterpoise": Milton & Robert Boyle', *Milton Quarterly*, 13 (1979), 15–17.

[70] Sargent, *The Diffident Naturalist*, pp. 161–62.

> *in eum quem non vides, propter ista quæ vides.* (III, 233)
>
> (You ought not to use your eyes as a Bruit, onely to take notice of Provisions for your Belly, and not for your Minde: Use them as a Man: Pry up into Heaven: See the things made, and enquire the Maker: Look upon those things you can see, and seek after Him whom you cannot see, and believe on Him you cannot see, because of those things you see.) (III, 282 (from 'The Citations English'd'))

Man might be limited, but he is instructed to search beyond his limits and to have faith in what is unseen because of what is seen. This also relates Boyle's method to his belief that natural philosophy serves to inspire wonder and faith in God.

In *Seraphic Love* Boyle expands on the trope of the *via negativa* with the idea that visual stimulation is supposed to transport you beyond its limits in wonder. On the prettiness of creatures he writes:

> God did ne're intend them to terminate our Love, but only by our Eyes to exalt our Faith above them, and by the beauties, our sight can apprehend, to raise us to a Confidence, that there is in their Author more than we can either see, or comprehend. (I, 87)

The end point is not the creature but the Creator. Boyle also describes this way of looking by an analogy of looking at a picture of your mistress through its crystal cover. The glass is pure and lovely, but it is not the chief business of your eye, nor do you terminate your sight in it, but rather you look through and beyond to the image itself (ibid.). Boyle also expresses this with an instrumental analogy:

> Me-thinks, *Seraphick* and our common *Lovers* behold exteriour beauties with a Difference resembling that, wherewith Children and Astronomers consider *Galileo*'s Optick Glasses, [...] which th'one prizes most, for what they Appear; the other, for what they Discover. For Children contenting themselves to wonder at the Length, and fall in Love with the Workmanship, and Gildings of the Tube, do thus but Gaze Upon them, whereas Astronomers Look Through them; and, scarce taking notice of the unusuall Ornaments, or the shape, imploy them to find out unknown Lights in the Skie, and to descry in Heaven bright Stars, unseen before, and other Cœlestiall Novelties and

> Beauties. (I, 88)

Children settle their gaze on the decorative object that is the telescope, but astronomers look *through* it to discover new and unseen beauty in the heavens. The analogy is similar to his consideration of the difference between a child and a philosopher admiring a rare book of hieroglyphics, and incorporates the methods of the natural philosopher — methods of observation and examination — into his search for God.

As Daston and Park so shrewdly observe, the passion of wonder 'register[s] the line between the known and the unknown'. They (and numerous other scholars) note that there is a strong relationship between Boyle's spirituality and his natural philosophical practices, particularly observing that the investigation of the natural world and the sense of wonder it provokes is for Boyle an act of worship in itself in that it affirms the existence of and our dependence on God.[71] Other scholars suggest more methodological links between Boyle's religion and his science. Hunter suggests that Boyle's 'obsessive practices' as an experimenter are related to the fact that he was so 'assiduous in his spiritual exercises'.[72] Lawrence Principe also argues convincingly that there are elements of Boyle's essay writing style used in his natural philosophical works which show stylistic and pedagogic influence from his earlier interest in romance and his own exhortatory moral writings.[73] Principe demonstrates a 'clear progression' from:

> The "Scripture Observations," in which texts give rise to moral messages, through the early *Occasional Reflections*, in which daily events give rise to moral messages, to Boyle's early chemistry, in which experimental results give rise to moral messages.[74]

Whether it is of scripture, daily life, or experiment, observation and reflection contribute to moral understanding.

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[71] Daston and Park, p. 13.

[72] Michael Hunter, 'The Conscience of Robert Boyle: Functionalism, 'Dysfunctionalism' and the Task of Historical Understanding', in *Renaissance and Revolution: Humanists, Scholars, Craftsmen and Natural Philosophers in Early Modern Europe*, ed. by J. V. Field and Frank A. J. L. James (Cambridge: Cambridge University Press, 1993), pp. 147–59 (p. 158).

[73] Lawrence M. Principe, 'Virtuous Romance and Romantic Virtuoso: The Shaping of Robert Boyle's Literary Style', *Journal of the History of Ideas*, 56 (1995), 377–97, (pp. 392–96).

[74] Principe, p. 393.

The influence of Boyle's religious thought on his experimental practice is most clearly seen in the flexibility of his epistemology, his embracing of nescience, and his inference of unknowns in a similar manner to apophatic theology. As Anstey describes, Boyle's corpuscularian philosophy was a middle way between contemporary metaphysical disputes, and allowed theory to proceed even though the debate was not yet settled.[75] It also provided a middle way between the spiritual and corporeal:

> betwixt visible bodies and Spiritual Beings there is a middle sort of Agents, invisible Corpuscles; by which a Great part of the difficulter *phœnomena* of Nature are produc'd, and by which may intelligibly be explicated those *Phænomena*, which 'twere absurd to refer to the former, and precarious to attribute to the latter.[76]

Invisible corpuscles provide an ontological solution, existing in a continuum between visible and spiritual. But this is not their only role. In using them to avoid the absurdity or precariousness of competing hypotheses, Boyle also attributes to them an explicatory function.

As we have seen, there is a complex relationship between the visible and invisible worlds that requires the experimental method and carefully controlled and demarcated experimental spaces to take natural philosophical knowledge beyond the limits of pure empiricism. But as well as practical experimental methods, Boyle also uses rhetorical and imaginative methods to think about and work on the invisible air.

The Visual Presentation of Experiment and Data

In this section I mainly focus on the use of illustrations in Boyle's publications on air, and their relationship to his use of verbal imagery, paying particular attention to the work of Steven Shapin, Simon Schaffer, and Bruno Latour on this subject. I also briefly consider Boyle's practices of aggregating and ordering information.

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[75] Anstey, *Philosophy of Robert Boyle*, p. 9.

[76] Boyle, 'Of the Atmospheres of Consistent Bodies', appended to *Spring, 1st Continuation*, in *Works*, VI, 167.

In Shapin and Schaffer's influential work *Leviathan and the Air Pump*, the authors argue that, 'Solutions to the problem of knowledge are solutions to the problem of social order.'[77] They assert that 'Robert Boyle sought to secure assent by way of the experimentally generated matter of fact' and delineate the methodology they believe he implemented to achieve this:[78]

> The establishment of matters of fact in Boyle's experimental programme utilized three *technologies*: a *material technology* embedded in the construction and operation of the air-pump; a *literary technology* by means of which the phenomena produced by the pump were made known to those who were not direct witnesses; and a *social technology* that incorporated the conventions philosophers should use in dealing with each other and considering knowledge-claims.[79]

Shapin and Schaffer argue that 'Boyle proposed that matters of fact be established by the aggregation of individuals' *beliefs*', and that 'Matters of fact were the outcome of the process of having an empirical experience, warranting it to oneself, and assuring others that grounds for their belief were adequate'. For Shapin and Schaffer, a fundamental element of this process is the 'multiplication of the witnessing experience'.[80] They propose that as well as trying to increase the number of direct witnesses to experiments, in his use of literary technology Boyle appeals to '*virtual witnessing*', going beyond mere reporting to create an experience in which the reader is a virtual witness to the experiments described.[81] Shapin and Schaffer claim that this is achieved by the following methods: the use of modesty and inclusion of reported failures to build trust in the author and his accounts of experiments; and the use of naturalistic pictorial images of the air pump and a high level of circumstantial detail in the reports to recreate the scene for the reader.

While the consideration of Boyle's methods in terms of material, literary, and

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[77] Shapin and Schaffer, p. 332.

[78] Shapin and Schaffer, p. 23.

[79] Shapin and Schaffer, p. 25. See also, Shapin, 'Pump and Circumstance', (pp. 482–84). Much of 'Pump and Circumstance' is duplicated in *Leviathan and the Air Pump*. For the rest of this argument I just cite from the book.

[80] Shapin and Schaffer, p. 25.

[81] Shapin and Schaffer, p. 60.

social technologies provides a useful and valid structure for analysis, there are also several ways in which I believe the arguments of *Leviathan and the Air Pump* need to be challenged. For example, the importance to the argument of invoking actual witnesses seems disproportionate to the actual frequency of occurrence of this practice in Boyle's experimental writings. Similarly, as Sargent has shown, the social status of such witnesses does not seem to receive the same emphasis in Boyle's writings as it does in Shapin and Schaffer's argument.[82] The aspects of Shapin and Schaffer's argument I question in this chapter are the details of Boyle's literary technology, which I believe have been subtly misinterpreted. My reading results in a slightly different interpretation of the role of the reader or 'virtual witness', and of the underlying presumption of the degree to which Boyle was concerned with persuading assent to his hypotheses.

The concept of virtual witnessing is sound. As Shapin and Schaffer describe it:

> The technology of virtual witnessing involves the production in a *reader's* mind of such an image of an experimental scene as obviates the necessity for either direct witness or replication. [...] The validation of experiments, and the crediting of their outcomes as matters of fact, necessarily entailed their realization in the laboratory of the mind and the mind's eye.[83]

They also note that the 'same linguistic resources' could be used 'to encourage the physical replication of experiments or to trigger in the reader's mind a naturalistic image of the experimental scene' (ibid.). These assertions hold up against Boyle's statements of intention in the preface to *Spring of the Air.* Boyle acknowledges that while he thought his nephew, the wealthy Lord Dungarven to whom the work is addressed, might be able to repeat his experiments, he also foresaw that the expense and difficulty would likely prohibit most men from trying them. He writes:

> I thought I might doe the generality of my Readers no unacceptable peace of service, by so punctually relating what I carefully observ'd, that they may look upon these Narratives as standing Records in our new Pneumaticks, and need not reiterate themselves an Experiment to

[82] Sargent, *The Diffident Naturalist*, p. 156.

[83] Shapin and Schaffer, p. 60.

> have as distinct an Idea of it, as may suffice them to ground their Reflections and Speculations upon. (I, 144)

Boyle hopes that his accounts will be sufficient to obviate the need for readers to perform the experiments themselves. The notion of ‘look[ing] upon these Narratives as standing Records’ contains within it a hope for a reclassification of the experimental accounts. Although they are near synonyms, *Narratives* places a greater emphasis on the subjective act of narration while *Records*, particularly as modified by *standing* which implies assent to factuality, is more detached from individual human agency. Boyle hopes that his punctilious relation and careful observation will elevate his narratives into a factual form with more authority and objectivity — a part of the trust element of Shapin and Schaffer’s literary technology. Because of the reliable nature of these *standing Records*, Boyle intends that his readers will not need to reproduce the experiment themselves in order to have a distinct idea of it. This is captured to some degree by Shapin and Schaffer’s description of the creation in the mind of ‘an image of an experimental scene as obviates the necessity for either direct witness or replication’. However, there is a silent slippage between thought and visual image in the move from Boyle’s ‘distinct [...] Idea’ to Shapin and Schaffer’s not quite synonymous ‘image of an experimental scene’, which implies a process in the reader’s mind that needs further investigation.

There is a visual element to Boyle’s words, particularly in his lexical choices for the responsive thoughts of the reader: *Reflections and Speculations*. These words appear frequently throughout Boyle’s text with this same context and are both words for thought with striking visual connotations: a *reflection* being an image returned to the observer, particularly in a mirror, and *speculation* deriving from Latin *speculari* (to watch, observe, examine) and *specere* (to see or look). There are three points to note. First, while Boyle does not deny visuality to the distinct idea of the experiments, it is not the distinct idea itself, but the thoughts of the reader provoked by it that are couched in visual terms. Second, Boyle does not use a language of simple observation or seeing, but a language loaded with associations of the mediated visual access provided by instruments. *Reflection* and *speculation* both have catoptric associations (*speculation* is also related to *speculum*, the Latin for mirror), and the idea of *grounding* reflections and speculations, as well as being synonymous with the idea of basing further thoughts upon the secure experimental foundation provided by Boyle as a distinct idea, is also potentially suggestive of the practice of grinding lenses and curved mirrors (such as those used in the reflecting telescopes built by Hooke and Newton). Third, and most significant, the purpose of creating the distinct idea of the experiment is not to persuade the reader to Boyle's hypothesis, but to facilitate and stimulate the reader's own thoughts about the experimental facts. These three points combine to suggest a process which is much more participatory than the rather passive feel of Shapin and Schaffer's virtual witnessing. The idea of witnessing as it occurs in Boyle's writing is not just in the distinct idea, but is also encapsulated in the spectative aspects of *reflection* and *speculation*, and thus thought itself is implicated in the act of witnessing the experiment. The semantics of instruments and the active nature of *grounding* also contribute to this participatory feel, echoing the ideas of the mind as an instrument discussed in the previous section, highlighting the interpretative act of the reader as observer, and placing him in command of the tools required for this act almost as an experimenter in his own right.

Shapin and Schaffer observe that 'We usually think of an experimental report as a narration of some prior visual experience: it points to sensory experiences that lie behind the text', and suggest that we expand this notion: 'we should also appreciate that the text itself constitutes a visual source.'[84] It is not just the verbal text that forms the literary technology of Boyle's method: the pictorial illustrations play an important role too. Shapin and Schaffer interpret Boyle's images as 'an attempt at detailed naturalistic representation', which function as 'mimetic devices'.[85] They claim that:

> By virtue of the density of *circumstantial detail* that could be conveyed through the engraver's laying of lines, they imitated reality and gave the viewer a vivid impression of the experimental scene. The sort of naturalistic images that Boyle favoured provided a greater density of circumstantial detail than would have been proffered by more schematic representations. The images served to announce, as it were, that 'this was really done' and that 'it was done in the way stipulated'; they allayed distrust and facilitated virtual witnessing.[86]

The authors refer to the use of cut away sections and shadowing in the illustration of the

[84] Shapin and Schaffer, p. 61.

[85] Shapin and Schaffer, pp. 61, 62.

[86] Shapin and Schaffer, p. 62.

air pump in *Spring of the Air* (see Fig. 2.1), and the inclusion of details such as a dead mouse in the receiver and depicted experimenters (presumably referring to plates 1 and 5 of *Spring, 1st Continuation*, although this is not clearly stated), as the sort of circumstantial detail that helps recreate the scene for the reader. They write: 'This is not a picture of the 'idea' of an air-pump, but of a particular existing air-pump.'[87] Shapin and Schaffer connect this use of pictorial illustration to Boyle's verbal methods of prolixity and circumstantial detail as being necessary for creating trust and facilitating virtual witnessing.

This argument for the function of the pictorial elements of the text is persuasive to some degree, and certainly I agree that we need to consider the text as a visual artefact as well as a verbal one. However, I think Shapin and Schaffer's analysis is too simplistic and their claims too widely applied. There are three questions I wish to raise: the question of the paucity of pictorial illustration in Boyle, the question of the subject matter, and the question of whether the function of the illustrations is mimetic and its purpose persuasive.

Shapin and Schaffer do not directly address the fact that Boyle's works were not extensively illustrated. *Spring of the Air* contains just one illustrated plate depicting the air pump and other equipment, gathered as a collection of sixteen figures on one page. There are no other illustrations and no illustrations at all of experiments or phenomena in this work, and yet *Spring of the Air* is one of the main texts supporting Shapin and Schaffer's argument about illustration. This paucity is alluded to in their statement, 'Producing these kinds of images was an expensive business in the mid-seventeenth century and natural philosophers used them sparingly' but is otherwise ignored. Dismissing the absence of further plates as a cost saving exercise is rather disingenuous considering Boyle's extensive wealth, the astronomical cost of the air pump itself, and the 'great attention' Shapin and Schaffer otherwise attribute to Boyle's role in the 'manufacture of these images'.[88] Similarly, while extensively illustrated natural philosophical works may not have been *de rigueur* they were not unheard of. As well as Hooke's *Micrographia*, examples include the first edition of William Gilbert's *De Magnete* (1600), which contained thirty-two illustrations across a two hundred and forty page work, not including inhabited initials and printers' ornaments. On the continent,

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[87] Shapin and Schaffer, p. 61.

[88] Ibid.

Otto von Guericke's *Experimenta nova (ut vocantur) magdeburgica de vacuo spatio* (1672) contained twenty illustrations (see for example Fig. 2.2) across a two hundred and forty-three page work, as well as an illustrated title page and an author portrait.

Fig. 2.2. Otto von Guericke, *Experimenta nova (ut vocantur) Magdeburgica de vacuo spatio* (Amsterdam: J. Jansson à Waesberge, 1672), plate 11.

The plate from *Spring of the Air* does render the depicted apparatus naturalistically in its use of shadowing, and indeed in its use of linear perspective, which Shapin and Schaffer do not mention. However, there are also many aspects about the plate that are not naturalistic. I would argue that the use of cut-away sections (see Fig. 2.1, Boyle's figure 15) is in fact a move away from naturalistic representation (although it does of course add circumstantial detail) and, like the exploded multipart piece depicted in Boyle's figure 2, is more to do with facilitating an understanding of the apparatus and its workings than recreating its actual visual appearance in the experimental scene. It is also notable that the items are all floating in white space — only one (figure 8) casts any background shadow. None of the items are to scale (figure 2 for example is a magnified view of a part in figure 1) nor do they bear any locational relation to the other figures in the plate. Compared to the engravings of experimental scenes more popular on the continent, which, even when they also included schematic illustrations of apparatus, were often naturalistically represented (see for example Fig. 2.2); or to the illustration in Boyle's own *New Experiments and Observations Touching Cold, or an Experimental History of Cold, Begun* (1665) in which a cross section of the experimental apparatus is depicted within its naturalistically illustrated outdoors setting of earth and trees (IV, 362); or the frontispiece to his *Medicina Hydrostatica: or, Hydrostaticks Applied to the Materia Medica* (1690)[89] in which the equipment depicted, although still schematic in its labeling, is shown laid out on a table with the legend on a banner backdrop (see Fig. 2.3), the plate from *Spring of the Air* does not appear to be naturalistic or mimetic at all. It might be three dimensional, but it is still schematic and the items depicted are generic. The way the figures are used by Boyle in his lettered cross-reference to them in detailed passages explaining the apparatus in the text, also supports this assertion by suggesting that the verbal and visual information supplied is intended to facilitate the understanding or recreation of the equipment. This does in turn help the reader to accurately visualize what happens in the experiments, but it is different to naturalistically recreating the experimental scene.

Another important consideration related to the paucity of illustration, is the subject matter. In *Spring of the Air*, Boyle chooses to illustrate the apparatus only. He does not show any of the experiments (there is nothing in the receiver depicted in Boyle's figure 1 of Fig. 2.1) or any of the resultant phenomena, and neither does he provide any visual aids to help the reader understand his hypothesis about the spring of the air.

[89] Hereafter *Medicina Hydrostatica*.

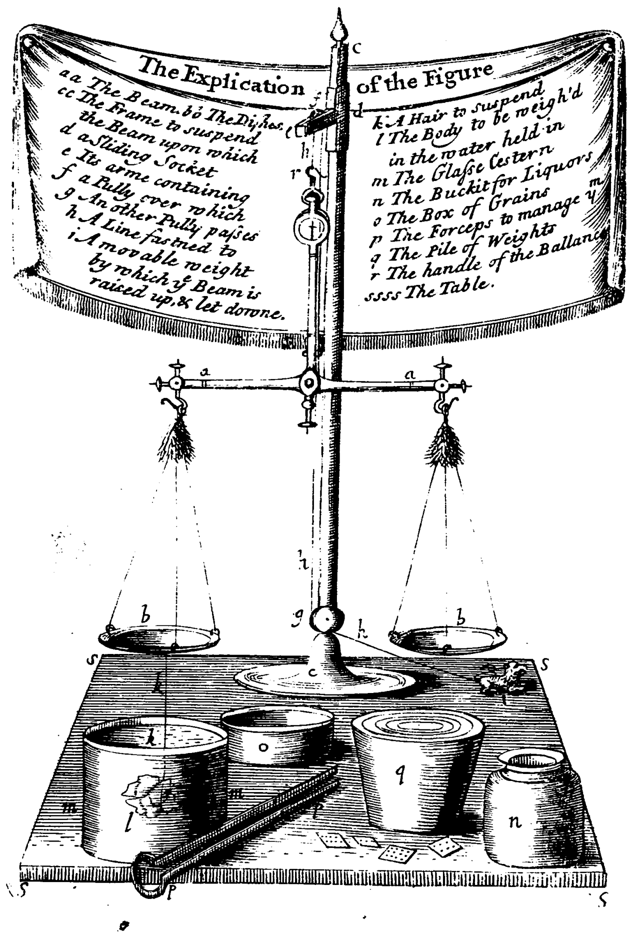

Fig. 2.3. Robert Boyle, *Medicina Hydrostatica* (London, 1690), plate 1 (cropped). Photo: © British Library Board. Image published with permission of ProQuest. Further reproduction is prohibited without permission.

On examination of the other images published in Boyle's works we find similar tendencies throughout his oeuvre, with some small variation. On the whole illustration is sparse. The most extensively illustrated work is *Spring, 1st Continuation*, which contains nine plates, most made up of groups of figures. This is one of the most 'naturalistic' collections of images (in Shapin and Schaffer's sense) with extensive use of body shadowing to create depth and weight to the depicted figures. However, in some cases the text that labels the figure and gives the page reference is found 'inside' the body of the depicted receiver. Where this occurs, the text is obscured by this body shading, possibly suggesting that the images were originally drawn up and labelled without shading and that this was added at a later stage in the process (see Fig. 2.4, particularly figure 2 in the bottom right).

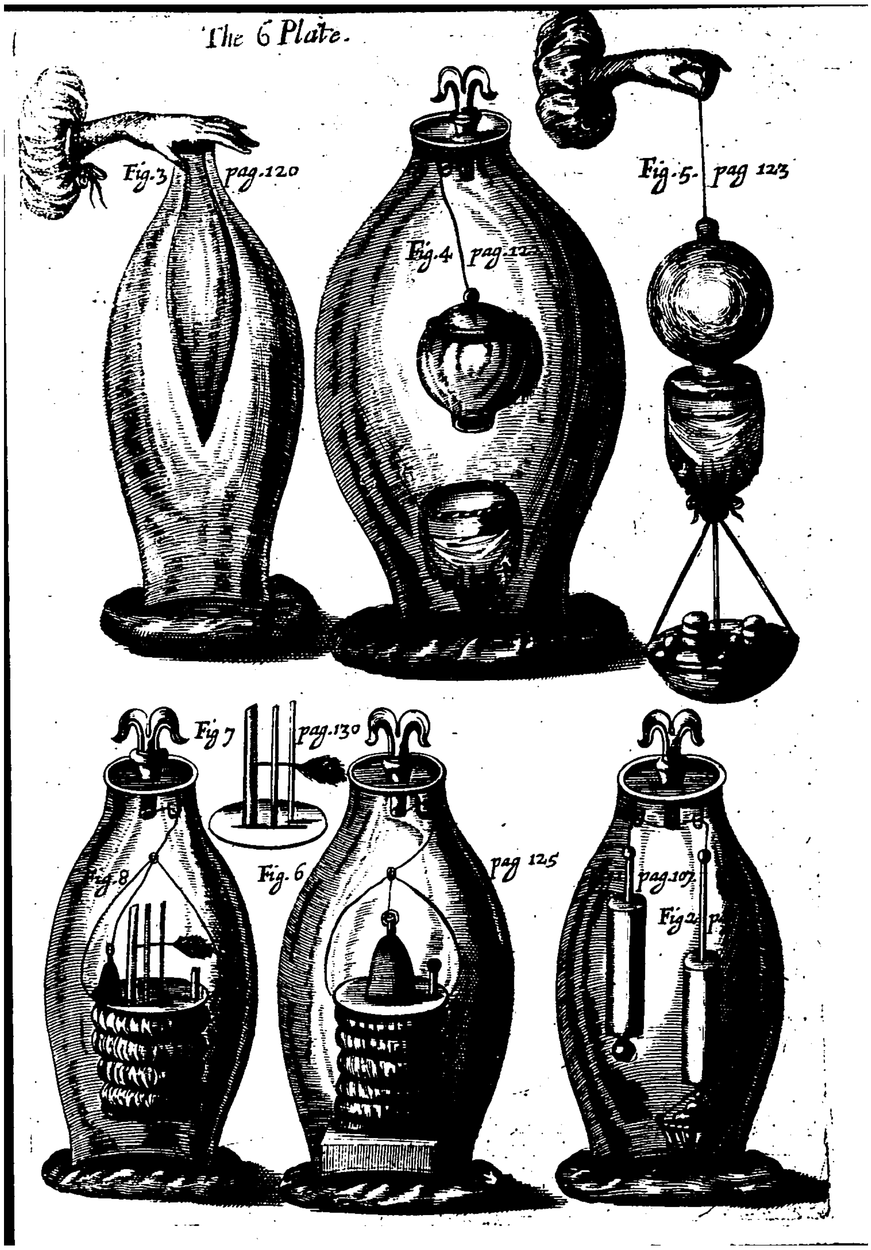

Fig. 2.4. Robert Boyle, *Spring, 1st Continuation* (London, 1669), plate 6.
Photo: © The Huntington Library, San Marino, California.

The majority of the figures in the nine plates of *Spring, 1st Continuation* include some gesture towards background, denoted either by shading to indicate a floor or surface, or by cast shadows from the object, or both. In some cases, multiple figures are placed on the page as if they were on the same surface. However with one exception — figure 1 of plate 5, which depicts a practitioner working with equipment on the roof of a building in order to show the set up of a singularly large experiment (see Fig. 2.5) — these still do not depict actual scenes that might help the reader imagine the laboratory setting. Even the naturalism of the image of the building is distorted by the inclusion in the same plate of figures 2–4, a collection of barometers at a different scale that appear on the page at the same height as the building, suspended in mid-air by disembodied hands, and decorated with an elaborate bow.

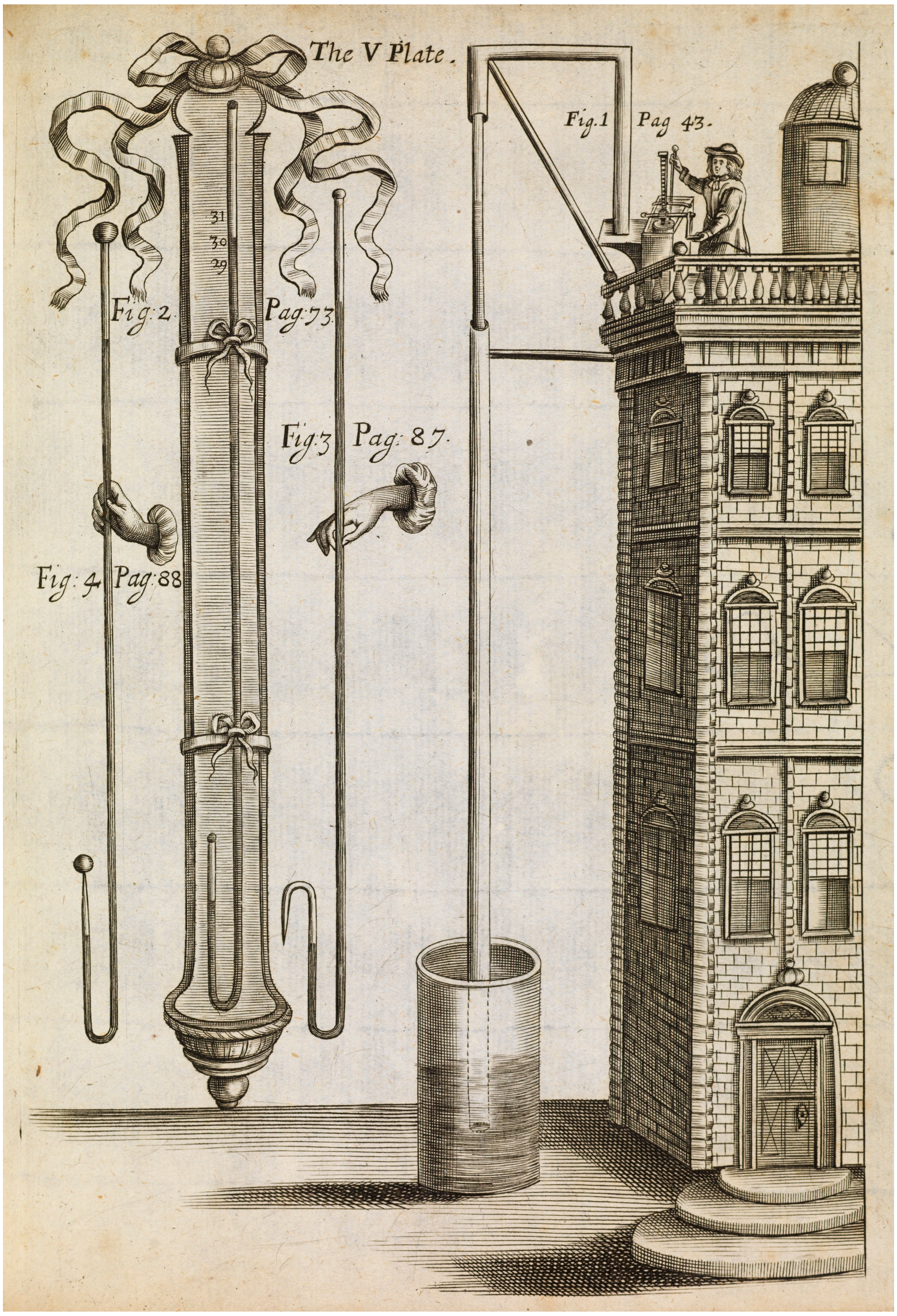

Fig. 2.5. Robert Boyle, *Spring, 1st Continuation* (London, 1669), plate 5.
Photo: RS.9473 © The Royal Society.

Apart from the first plate of *Spring, 1st Continuation*, which depicts the air pump, most of the plates show groups of figures gathered artificially into one scheme (as in Fig. 2.4). The focus is still on depicting apparatus, but while the second plate is generic — depicting details of the air pump — the other plates depict specific setups inside the receivers for specific experiments, cross-referenced with the text. However we are still not shown any results or visual interpretations of hypotheses, and there is still a sense of disconnection because, apart from the first plate (showing the air pump with a dead mouse in the receiver as discussed by Shapin and Schaffer), the receivers are divorced from the pumps that give them their experimental context. Four of the figures include parts of apparatus held by disembodied hands (see figures 3 and 5 of Fig. 2.4 and figures 3 and 4 of Fig. 2.5), but unlike the inclusion of the experimenter in figure 1 of plate 5 (Fig. 2.5), these are very disjointed from the reality of the scene, not least because the hands are distinctly female hands and while some of the witnesses were women, all of the practitioners of Boyle's experiments were men. The other works with multiple plates — *Hydrostatical Paradoxes, Made out by New Experiments, (For the Most Part Physical and Easie)* (1666) and *Spring, 2nd Continuation* — contain only detailed images of equipment, which, while three dimensional, have a very schematic rather than naturalistic feel.

In terms of the subject matter of the illustrations associated with the air pump and pneumatic experiments, it is intriguing that there are no illustrations of phenomena, or of the hypothesized movement or make up of the air. I suggest that the decision not to depict such things relates to Boyle's nescience about causes and his desire for the reader to ground their own reflections and speculations. Aside from a diagrammatic illustration of the passage of light through a prism in *Experiments and Considerations Touching Colours* (1664), none of Boyle's illustrations contain visual representations of this sort of physically explanatory phenomena, and although the lines of the prism diagram record the movement and behaviour of light, the lines also reproduce what can be simply and visibly observed as beams of light (IV, 103).

In *Spring of the Air*, although Boyle provides no illustration for his hypothesis, the verbal description is in fact very visual. Boyle describes his notion that there is a spring or elastical power in the air, giving a corpuscular description of the air as made up of or abounding with particles which can be bent or compressed by the weight of the atmosphere or other bodies and which try to resist that pressure by unbending themselves as much as possible (I, 165). This is consolidated by use of analogy:

> This Notion may perhaps be somewhat further explain'd, by conceiving the Air near the Earth to be such a heap of little Bodies, lying one upon another, as may be resembled to a Fleece of Wooll. For this (to omit other likenesses betwixt them) consists of many slender and flexible Hairs; each of which, may indeed, like a little Spring, be easily bent or rouled up; but will also, like a Spring, be still endeavouring to stretch it self out again. (Ibid.)

Boyle continues in this vein, expounding further similarities, again very visual, between 'both these Haires, and the Aerial Corpuscles to which we liken them' (ibid.). The image of a heap of particles, or little springs would be easy to illustrate but instead the verbal analogy takes on the role of a pictorial illustration, rather than being supplemented by one.

Cristoph Lüthy describes the paucity of early modern atomic illustration more widely, pointing out that Gassendi's thousands of pages of Epicureanism remain pictureless, despite many attempts to describe atomic shapes verbally, and that of the seventy-nine editions of Lucretius's *De Rerum Natura* printed between 1473 and 1725, many with lavish illustrations and frontispieces, only one edition — the third edition of Thomas Creech's English translation of 1683 — had anything even approaching a graphic representation of atoms, depicting the motes of dust in a sunbeam that are used by Lucretius as an analogy for atoms in Book 2.[90] Lüthy does however describe Descartes's graphical representations of otherwise invisible elementary particles in publications going back to 1637, giving a notable precedent for this sort of pictorial illustration.[91]

In the *Defence* and *Examen*, published in response to criticisms of *Spring of the Air* made by Franciscus Linus and Thomas Hobbes, we find the only conceptual images in Boyle's oeuvre (see Fig. 2.6). On a single plate at the beginning of the work are gathered six figures. Four of these depict equipment in Boyle's usual fashion, corresponding to the text and his debate with Linus and Hobbes. Figures 4 and 6 however are notably different. Figure 6 is a diagram that offers a visual explanation for the mathematical problem of the *Rota Aristotelica*, and figure 4 depicts the idea of air

[90] Lüthy, 'Atomist Iconography', p. 122.

[91] Christoph Lüthy, 'Where Logical Necessity Becomes Visual Persuasion: Descartes's Clear and Distinct Illustrations', in *Transmitting Knowledge*, ed. by Kusukawa and Maclean, pp. 97–133 (p. 101).

particles as coiled springs. Both are referred to in the separate section, 'An Explication of Rarefaction', which is actually authored by Hooke and not Boyle.[92] It is Hooke in *Micrographia* who is the first person to visually depict a hypothetical arrangement of atomic particles (see Fig. 1.4).

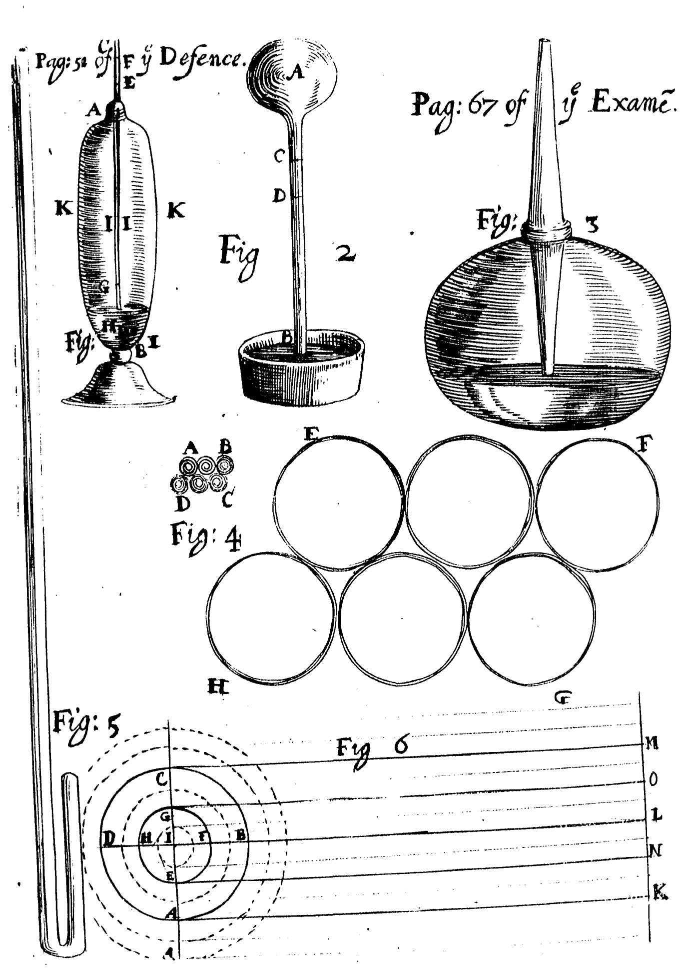

Fig. 2.6. Robert Boyle, *Defence* and *Examen* (London, 1662), plate 1 (cropped). Photo: © British Library Board. Image published with permission of ProQuest. Further reproduction is prohibited without permission.

The absence of any such image of the hypothetical structure of the air in *Spring of the Air* (and indeed any of Boyle's other works bar Hooke's illustration) does have a

[92] On authorship, see Boyle, *Works*, III, 83, note a. For a more detailed consideration of Hooke's contribution to the explanation of the elasticity of the air in *Defence* and *Examen*, see Antonio Clericuzio, 'The Mechanical Philosophy and the Spring of the Air: New Light on Robert Boyle and Robert Hooke', *Nuncius*, 13 (1997), 67–75.

particular effect on the way in which the work operates as persuasion, in particular on the relationship between the distinct idea and the reflection and speculation grounded upon it. The detailed and highly visual nature of the textual descriptions of the hypothesized spring of the air and the use of analogy and image as detailed above, suggest Boyle wants the reader to be able to visualize his hypothesis. It also proves that the idea has a clear form in Boyle's mind, and that it could therefore be pictorially illustrated if he wished (indeed as Hooke does two years later in the *Defence* and *Examen*). As Shapin and Schaffer assert, the engravings of apparatus give the readers images that can be duplicated in the mind, but without such pictures, the visualization of the hypothetical description of the nature of the air requires different processes. By using verbal description and analogy Boyle makes the reader engage the imagination and contemplate the way in which the relationship holding the analogy together works. This is much closer to the act of inference Boyle himself undergoes to arrive at his own hypothesis from observed experimental phenomena, which don't reveal the air itself but merely its effects on visible bodies. Boyle uses the difference between the visuality of a picture and the visuality of verbal description to add something to the reader's experience beyond just being a passive witness. In the preface Boyle states his hope, 'that the various hints to be met with in the following Letter, will (at least) somewhat awaken mens thoughts, & excite them to new speculations' (I, 146).

The co-opting of the reader as a participant in the work of natural philosophy, as a thinker and interpreter of experimental outcomes rather than a mere witness, sits well with the sense found throughout Boyle's work of it being a wider, and indeed collaborative project. He frequently makes reference to ways in which the work may be developed, for example by use of better instruments, different conditions, or by people with different specialities such as mathematics. Boyle's term 'the Invisible College' is particularly provocative here. He uses it in letters of the late 1640s to refer to the network of natural philosophers with whom he was in contact, but it is tempting to extend the idea of invisibility beyond the fact that these scientists were not at that time united by a formal affiliation, to include notions about the methods of developing knowledge through the work that could take place in the sort of mental laboratory that this extended conception of virtual witnessing facilitates. In *Spring of the Air* Boyle establishes the reader as a virtual witness to what is attestable and picturable fact, that is, the equipment and execution of the experiments, and then within that same mental space encourages the reader to reflect for him or herself, not just as a witness, but as an intellectual participant. The reader is presented with Boyle's ideas, but not constrained by their pictorial depiction, and the processes of imagination required to visualize Boyle's verbal descriptions and hypotheses provide the reader with the imaginative tools to respond to, and indeed reflect and speculate on, the observed phenomena itself.

The lack of pictorial illustration also allows Boyle to accommodate the movement and change of the corpuscles, and furthermore of his own imagery. Boyle's aerial corpuscles aren't static, and while an engraved image might have made more immediately accessible the particles he was describing, it would have struggled to capture the dynamic nature Boyle's descriptions ascribe to them, for example in the continual battle between compression and unbending and stretching, or the air's anthropomorphic efforts to insinuate itself into every gap in the stop. Boyle's images also change according to his descriptive needs, for example at the end of the analogy between air and a fleece of wool, he admits that in one aspect — the air's powers of self-dilation — it is more like a dry sponge than wool, but that the latter comparison was used 'on this occasion' because of its particulate structure. Similarly, the flexibility afforded when the image is held in the imagination rather than on the page allows Boyle to entertain other possibilities or potential objections to his theory, understand them, and then return to his original idea, allowing images to form, transform, and reform in the mind. Around ten pages after the fleece of wool analogy, Boyle considers an objection against the compactness and pressure of the air:

> That we finde this very Air to yield readily to the motion of little Flies, and even to that of Feathers, and such other light and weak Bodies; which seem to argue, that the particles of our Air are not so compress'd as we have represented them. (I, 169)

This new image allows the particles to relax in our mind's eye as we imagine this different potential state, but Boyle soon returns to his fleece of wool analogy and the original image is restored to the mind.

Bruno Latour uses Shapin's essay, 'Pump and Circumstance', to support his argument for 'immutable mobiles'.[93] For Latour, changes in scientific thinking occur not because of large conceptual shifts in thinking, but because of 'simple modifications in the way in which groups of people argue with one another using paper, signs, prints

[93] Latour, p. 7.

and diagrams.'[94] However, he also recognizes the potential for this deflating strategy to rid us of one great mystical divide, only to replace it with another kind of mysticism if the researcher dealing in prints and images believes in the power of signs and symbols isolated from anything else. He seeks a way of holding the focus to make this strategy useful, insisting that we must first consider, 'in which situations we might expect change in the writing and imaging procedures to make any difference at all in the way we argue, prove and believe.'[95] He achieves this by limiting the scope of enquiry to the construction of hard facts, which he figures with a model of competitive assent:

> Who will win in an agnostic encounter between two authors, and between them and all the others they need to build up a statement S? Answer: the one able to *muster on the spot the largest number of well aligned and faithful allies*. [...] My contention is that writing and imaging cannot by themselves explain the changes in our scientific societies, except insofar as *they help to make this agnostic situation more favorable*. [...] We need, in other words, to look at the way in which someone convinces someone else to take up a statement, to pass it along, to make it more of a fact, and to recognize the first author's ownership and originality.[96]

With the prioritization of these concerns, Latour — with a strongly Eisensteinian outlook — ascertains that the most important factors for visualization, print, and writing are the mobilization and stability of the things one is attempting to convey: 'you have to invent objects which have the properties of being *mobile*, but also *immutable, presentable, readable* and *combinable* with each other', denoting such objects as 'immutable mobiles'.[97]

Latour is of course correct that this is one element, but his argument limits itself with its narrow focus on the construction of hard facts and also limits the scope of scientific texts with its focus on the mustering of assent. Science is advanced, not just by proofs, but also by the posing of questions and highlighting of uncertainties, which stimulates further enquiry. Indeed, if we are looking for moments of change in the way

[94] Latour, p. 3.

[95] Latour, p. 4.

[96] Latour, p. 5.

[97] Latour, p. 7.

we argue, prove, and believe, then surely, while the assertion of facts may be a part of the process of establishing a new scientific idea, it will not be the whole process. This emphasis on hard fact in the context of the idea of immutable mobiles confuses two types of certainty: the certain immutability of the inscription (be it writing, image, or printed text), and the factual certainty of the content inscribed. As is also found in the argument of Shapin and Schaffer, there is a silent slippage between the distinct idea formed by the text and assent to the hypothesis. Depending on its physical inscription, a list of questions, unknowns, or hypotheses could just as easily be considered an immutable mobile as a statement of fact or set of assertions. By limiting his discussion in this way, Latour misses the fascinating interplay between hard fact and hypothesis that reveals some of the subtleties of the role of the imagination in cutting-edge science of any period, and which is certainly to be found in Boyle's work on air.

In his discussion of Boyle — which leans heavily on Shapin's essay — Latour, like Shapin and Schaffer, limits the role of the reader, writing of Boyle's 'disciplining' of his (virtual) witnesses.[98] If scientific writing is entirely persuasive and only about mustering allies to a particular position, then the reader's function as an interpreter, thinker, and (as I believe) intellectual participant in the development of knowledge is seriously curtailed to merely agreeing or disagreeing with the author.

Latour observes the staging qualities of Boyle's work, the creation of the 'new laboratory'. However he fails to distinguish the certainty of the setting from the (far lesser) certainty of the phenomena to be considered. He writes:

> it is possible to overestimate the inscription, but not the setting in which the cascade of ever more written and numbered inscriptions is produced. What we are really dealing with is the *staging* of a scenography in which attention is focused on one set of dramatized inscriptions. The setting works like a giant 'optical device' that creates a new laboratory, a new type of vision and a new phenomenon to look at. [...] The earlier we go back in history of science, the more attention we see being paid to the setting and less to the inscriptions themselves. Boyle, for instance, in the fascinating account of his vacuum pump experiment described by Shapin (1984), had to invent not only the phenomenon, but the instrument to make it visible, the set-up in which the instrument was displayed, the written

[98] Latour, pp. 10, 19.

> and printed accounts through which the silent reader could read 'about' the experiment, the type of witnesses admitted onto the stage, and even the types of commentaries the potential witnesses were allowed to utter. 'Seeing the vacuum' was possible only once all these witnesses had been disciplined.[99]

Latour's emphasis on the setting as an optical device resonates with my point about the demarcation of experimental spaces as necessary to be able to 'see' phenomena. However, although he observes that less attention is paid to the inscriptions themselves; tantalizingly writes of Boyle's *invention* of phenomena; and places 'Seeing the vacuum' inside quotation marks, Latour — like Shapin — switches the focus to the assent of witnesses and fails to note or discuss the fact that the phenomenon of particulate air is not actually made visible anywhere other than in the reader's imagination, and that the verbal presentation is that of a tentative hypothesis, not hard fact. Boyle may be persuasive as to the factual nature of the setting and empirical data presented, but this is not the whole story and the distinction between the two modes of factual account and hypothetical explanation needs to be maintained. That Latour fails to maintain this distinction is made clear when he asks: 'Can we summarize why it is so important for Brahe, Boyle, Pasteur or Guillemin to work on two-dimensional inscriptions instead of the sky, the air, health, or the brain?'[100] What has been inscribed by Boyle is not the air, but some factual observations about experiments performed on the air and some hypotheses about the nature of air based on these observations. The contrast between the factual description of the setting and observations (aided by the material representations of apparatus) and the hypothetical explanations offered (aided by non-material verbal descriptions), does not so much discipline the reader as create an experimental environment in which he or she can think. The development of the sorts of images found in Boyle's work (and in seventeenth century natural philosophy texts more widely) with their absence of conventional Renaissance framing devices such as a present human figure or an eye, emphasizes the growing importance of the reader and supports the notion of the reader as a participant. Without these devices, the reader becomes the witnessing figure or eye himself, with the material text becoming the apparatus for viewing the observed phenomena.

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[99] Latour, p. 19.

[100] Latour, p. 20.

As I show with Hooke, the idea that the text can operate as a piece of apparatus to help a practitioner 'see' is strongly felt in the methods Boyle uses to gather and order information on the page. In Boyle there is an impulse towards collection and aggregation, of gathering information together so it is, as Hooke recommends, 'at one view'. Much of Boyle's published works on air, in particular *Spring of the Air* and its two continuations, are collections of a vast array of Boyle's experimental reports, and *General History of Air* is a gathering together of experiments, observations, and testimonies from various sources. Even the more discursive works such as the *Defence* and *Examen* incorporate and aggregate various experimental accounts in the marshalling of evidence for their arguments. This accretive approach is also seen at a meta-level in Boyle's practice of utilizing methods from a range of different traditions and sources. As Sargent describes, his method is 'an eclectic synthesis of the best elements of what have come to be known as various empiricist, rationalist, and pragmatist traditions'.[101]

Sargent describes Boyle's repeated stress on the importance of collation and the orderly presentation of data. For example in *The Sceptical Chymist: or Chymico-Physical Doubts & Paradoxes* (1661), Carneades is praised for the way he 'laid them [the experiments] together in such a way, and apply'd them to such purposes, and made such Deductions From them, as I have not Hitherto met with.'[102] The deductions are implied to be a result not just of the experiments, but of how those experiments are laid together and applied, the imagery of laying them together suggesting at the least a visual metaphor for a verbal or mental gathering together of data, and possibly a literal and practical application. This sense of gathering information at one view is also seen in Boyle's use of tables and lists for numerical data and quantifiable experimental results (such as in *Medicina Hydrostatica* and *General History of Air*) and his creation of indexical summaries for his published works.

Although the Boyle archive is well known for its disarray, often presumed to be at the hands of subsequent scholars, Hunter, in his extensive work on Boyle's manuscript papers, suggests that its confusion is perhaps 'due less to depredations

[101] Sargent, *The Diffident Naturalist*, p. 10.

[102] Boyle, *Works*, II, 374. See also Sargent, *The Diffident Naturalist*, p. 182.

suffered by the archive after Boyle's death than to his own way of keeping it'.[103] He presents a convincing case that the chaos 'may have been more apparent than real' and that the data he was collecting was, to Boyle's mind, 'only useable if given a shape'. [104] Boyle uses lists, inventories, mnemonics, and colour coded stationery to systematize his writings.[105] However, the intention to deploy or arrange data thematically is not always fulfilled and remains untranscribed in his work-diaries in which notes are made by date rather than under heads.[106] One of his work-diaries is entitled, 'Philosophicall Entrys & Memorialls (of all sorts,) Here confusedly throwne together; to be Hence transferr'd to the Severall Treatises whereto they belong'.[107] Hunter writes that the 'the archive had an ordering which bore a significant relationship to Boyle's intellectual aims and methods' and argues that those aims were not towards the establishment of matters of fact (as much scholarship suggests) but for the interpretative use to which empirical findings are put.[108] Hunter notes that there is a tension found in Boyle's writing between clarity and accessibility and the need to represent adequately the complexity of his subject. This can be seen in the revisions made to his draft material, which rarely add to clarity and are not always even added in the most appropriate places.[109] I think we also see Boyle's struggle to manage his data in his frequent apologies in the prefaces to his published works for the inadequacies of his writing and for organizational problems such as misplacing certain notes. Richard Yeo argues that certain members of the Hartlib circle — in particular John Beale who corresponded with Boyle on the subject — 'sought to condense knowledge and information into an ordered structure that facilitated learning and recollection'. Boyle however, was 'far less interested in placing the facts and ideas thus acquired [i.e. from observations and experiments] in a sequence within some mnemonic grid', and Yeo further describes his 'refusal to condense and arrange material in the way they [Hartlib and Beale] demanded'. Yeo suggests that Beale's suggestions, which relied on memory techniques using 'highly structured

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[103] Michael Hunter, *Robert Boyle (1627–91): Scrupulosity and Science* (Woodbridge: Boydell Press, 2000), p. 121.

[104] Hunter, *Scrupulosity and Science*, pp. 121, 133.

[105] Hunter, *Scrupulosity and Science*, p. 132.

[106] Hunter, *Scrupulosity and Science*, p. 131.

[107] BP, 22/1, quoted in Hunter, *Scrupulosity and Science*, p. 131.

[108] Hunter, *Scrupulosity and Science*, pp. 121, 214.

[109] *Robert Boyle Reconsidered*, ed. by Hunter, 'introduction', p. 12.

arrangements of units', may have 'aggravated Boyle's existing suspicion of premature systems'.[110] Exploring a related idea, Ernan McMullin in his work on the place of hypothesis in Boyle's natural philosophy asserts that Boyle recognized the role of experiment in 'sorting between theoretical alternatives'.[111] I think that Hunter's, Yeo's, and McMullin's observations and arguments can be productively combined to give a holistic understanding of the tension between order and chaos in Boyle's work. Boyle tries to balance the need for clarity against the threat of reductiveness to his desire to recognize the true complexity of nature; to balance the need for order to give his thoughts shape against the nescient resistance of definitive structure; and to balance the possibilities of competing theories against each other without precluding any prematurely. Perhaps the issue of one of scale; Boyle's urge towards comprehensiveness is reminiscent of the maps of Jorge Luis Borges's 'Del rigor en la ciencia' ('On Exactitude in Science').

Ann Moss describes the use of 'more random', non-alphabetical systems of common-placing such as those constructed by Erasmus on chains of affinity or contrariety, writing that, 'The motivation behind apparently free ordering of this kind was the production of persuasive discourse, rhetorical invention, rather than a mapping of the known places of the universe of knowledge'.[112] This interpretation of Erasmus and systems of free, or perhaps freer, ordering can perhaps be applied to Boyle, whose nescience and resistance to artificial systematization is reflected in his reluctance to write or present his work in the ordered way suggested by Beale and Hartlib. We perhaps see it in *Spring, 2nd Continuation* where Boyle's initial attempt at writing experimental reports in a very terse, proto-tabular form, gradually expands back into his more customary narrative form over the course of the experiments. McMullin's idea that experiment is itself a sorting tool suggests that the principles of order Boyle was

[110] Richard Yeo, 'Memory and Empirical Information: Samual Hartlib, John Beale and Robert Boyle', in *The Body as Object and Instrument of Knowledge: Embodied Empiricism in Early Modern Science*, ed. by C. T. Wolfe and O. Gal (London: Springer, 2010), pp. 185–210 (p. 205).

[111] Ernan McMullin, 'Conceptions of Science in the Scientific Revolution', in *Reappraisals of the Scientific Revolution*, ed. by David C. Lindberg and Robert S. Westman (Cambridge: Cambridge University Press, 1990), pp. 27–92 (p. 56).

[112] Ann Moss, 'Locating Knowledge', in *Cognition and the Book: Typologies of Formal Organisation of Knowledge in the Printed Book of the Early Modern Period*, ed. by Karl A. E. Enenkel and Wolfgang Member (Leiden: Brill, 2005), pp. 35–48 (p. 44).

interested in were epistemological devices for discovering truths, not for imposing or categorizing them. As Boyle writes in *The Christian Virtuoso, Part II*:[113]

> The book of nature is a fine and large piece of tapestry rolled up, which we are not able to see all at once, but must be content to wait for the discovery of its beauty, and symmetry, little by little, as it gradually comes to be more and more unfolded, or displayed. (XII, 530)

Conclusion

Boyle's writings and the methods of his natural philosophical programme are characterized by a tension between his strong adherence to an epistemology of nescience and his desire to seek out and discover natural philosophical truths, and his belief that his inquisitive age would 'produce discoveries that will explicate divers of the more hidden mysteries of Nature' (IX, 373). This tension is felt in the presentation of his work, particularly in the high level of circumstantial detail — which speaks of a desire not to filter out any information at this stage — juxtaposed with more practical exigencies such as summary deferrals to experience. It is also seen in the seeming chaos of his archive, which both strives for the sort of order that can reveal patterns and new knowledge, and yet resists premature systematization.

An important part of Boyle's methodology is the embracing of experiment as a means of moving beyond superficial readings of nature that rely on observation and intuition alone, to a method that allows the isolating and testing of facts. This also allows for the study of objects that are otherwise impossible to observe, such as the invisible air. The experimental method is highly spatial in that it relies on the careful demarcation and control of experimental spaces in order to produce reliable testing, particularly when environmental factors are relevant, or indeed, the object in question. This concern is very strongly felt in the high level of attention paid to the integrity of the air pump. There is also a second kind of spatiality attached to Boyle's experimental method, and that is a mental spatiality. As Shapin and Schaffer suggest, Boyle uses literary technologies (including his descriptions and illustrations) to recreate the

[113] Ed. by Henry Miles, first published in *Works of the Honourable Robert Boyle*, ed. by Birch.

experimental scene in the reader's mind. However, unlike Shapin, Schaffer, and Latour, I believe that this technique of creating virtual witnesses is not so much to do with mustering assent for Boyle's hypotheses, as it is to do with creating mental laboratories, which facilitate the reader's own reflections and speculations, stimulate the sort of imaginative thinking necessary for illative knowledge, and allow him or her to engage in natural philosophical experiment as a participant.

Chapter 3

Isaac Newton: Absolute and Relative Space

Introduction

Newton's *Philosophiæ Naturalis Principia Mathematica* (1687, with corrected editions in 1713 and 1726) is a work intimately connected with space and spatiality. It does not have the same visuality of Hooke's observational work on micro space, or even of Boyle's sparsely illustrated, experimental work on the invisible air. It is spatial in a much more abstract sense, espousing a space that is mathematical and conceptual. And yet it concerns the real-world space that frames and makes sense of the interactions of bodies, which are fundamental to our understanding of the world.

It is in the *Principia* that Newton states his laws of motion, his inverse square law of universal gravitation, and his derivation of Kepler's laws of planetary motion. One of the key elements of Newton's work is that it moves beyond kinematics — the study or description of the motion of bodies without reference to the cause of that motion — to dynamics, i.e. the study of the forces and torques that effect motion. This changes the study of motion from being about geometry to being about processes of change over time. As with Boyle, whose verbal rather than pictorial illustrations allow the reader to imagine the movement of atoms and the compression and unbending of air particles in a mental laboratory, Newton needed methods that allowed him and his readers to be able to conceive of and work (mathematically) with these processes of change. There are two main tools he employs for this: the calculus and inertial frames of reference.[1] The inertial frame of reference — which is the subject of the second section of this chapter — allows for dynamics, for rates of change over time, to be understood, perceived, and to be measured. In some ways it is like the physically demarcated experimental spaces of Boyle's method, in others like the mental laboratories Boyle constructs for his readers.

In the first section of this chapter, I consider Newton's ideas — in the *Principia* and other works — about the purpose and practice of natural philosophy, and some of his statements that illustrate his thoughts about general questions of epistemology, key features of which are the assumption of the consistency of nature and the acceptance of

[1] I do not consider the calculus here as it is beyond the scope of this thesis, but there are interesting resonances with Hooke's idea of gathering data 'at one view' and corpuscularian conceptions of submicroscopic particles in its method, which works on the basis of ratios of aggregations of infinitesimally small parts of a whole.

contingent knowledge as having a vital role in natural philosophy. I also consider the way Newton's figures the limits of human knowledge in relation to God. In the second section, I give a description of Newton's concepts of absolute and relative space, and consider the epistemological and metaphysical issues arising from them. In the third section I investigate the relationship between God and space in Newton's writings and show that it has epistemological implications as well as metaphysical ones.

Through these considerations I show Newton's thought to rely heavily on notions of space and spatiality, not just as a subject, but as a way of thinking. I also show that although Newton posits the idea of absolute space, defining him as an absolutist does not seem to be a correct or uncomplicated attribution. Newton uses absolute space as a way of understanding and thinking about our relative experience of space, and to arrive at mathematically more precise calculations of movement. But the absolute is understood by means of the relative, and his exploration is intimately tied up with epistemology and notions of perception and thought.

Epistemology and the Frame of Nature

Amongst several undated manuscript drafts of a paper entitled 'A Scheme for Establishing the Royal Society', Newton offers a definition of the purpose and practice of natural philosophy:

> Natural Philosophy consists in discovering the frame & operations of Nature, reducing them (as far as may be) to general Rules or Laws, establishing those rules by observations & experiments, & thence deducing the causes & effects of things.[2]

Similarly, in Query 28 in the expanded *Opticks* (1718), Newton states:

> The main business of natural philosophy is to argue from phenomena without feigning hypotheses, and to deduce causes from effects, till

[2] Isaac Newton, 'A Scheme for Establishing the Royal Society', Cambridge University Library, Newton Papers, MS Add.4005, <http://cudl.lib.cam.ac.uk/view/MS-ADD-04005/21> [accessed 24 February 2014] (p. 2:6^{r}).

> we come to the very first cause, which certainly is not mechanical.[3]

These quotations summarize a number of key interrelated aspects of Newton's approach to natural philosophy: the complimentary roles of empirical evidence and deductive reasoning; Newton's aversion to feigned hypotheses; the principle of generalization; and the relationship between the observable rules of nature and our understanding of cause and effect. The first quotation also highlights an intriguing notion of spatiality implicit in the way Newton imagines his philosophical task: the idea of 'the frame [...] of Nature' creates an image of an underlying structure — some organizing principle that is figured spatially — waiting to be uncovered by the diligent philosopher. However, as I will demonstrate of Newton's concept of absolute space, this underlying frame has an ambiguous status, neither wholly literal nor wholly metaphorical. The idea of an underlying frame, and the key aspects of Newton's approach listed above, all point to two central themes in Newton's epistemology: the ideas of contingency and consistency.

The status of hypothesis and the relationship between theory and fact is a central concern, which leads to the contingent approach. Roger Cotes, in his preface to the second edition of the *Principia*, compares three classes of natural philosopher. He first describes the scholastics, 'wholly concerned with the names of things rather than with things themselves', and distinguishes from them those who — believing matter to be homogeneous and that form arises from the attributes of particles — reject that approach.[4] However, Cotes also criticizes these more modern philosophers (in particular Descartes and his theory of vortices), writing:

> But when they take the liberty of imagining that the unknown shapes and sizes of the particles are whatever they please, and of assuming their uncertain positions and motions, and even further of feigning

[3] Isaac Newton, *Philosophical Writings*, ed. by Andrew Janiak (Cambridge: Cambridge University Press, 2004), p. 130. Further references to this collection are denoted *PW* and given parenthetically in the text. The *Opticks* was first published in English 1704 with sixteen queries, and republished in Latin with an additional seven queries in 1706. It had a second edition in English in 1718 with thirty-one queries, and a third, virtually unchanged, in 1721, on which Janiak's text is based (see *PW*, p. xxxiii).

[4] Isaac Newton, *The Principia: Mathematical Principles of Natural Philosophy*, trans. by I. Bernard Cohen and Anne Whitman (Berkeley: University of California Press, 1999), p. 385. Further references to this edition are denoted *Principia* and given parenthetically in the text.

> certain occult fluids that permeate the pores of bodies very freely, […] they are drifting off into dreams, ignoring the true constitutions of things, which is obviously to be sought in vain from false conjectures, when it can scarcely be found out by the most certain observations. (*Principia*, p. 385–86)

Cotes condemns the taking of liberties, the making of uncertain assumptions, and the feigning of occult solutions as false conjecture and opposed to truth. He sums up: 'Those who take the foundation of their speculations from hypotheses, even if they then proceed most rigorously according to mechanical laws, are merely putting together a romance' (*Principia*, p. 386). He contrasts this with the third class of natural philosophers, with whom he groups Newton:

> They assume nothing as a principle that has not yet been thoroughly proved from phenomena. They do not contrive hypotheses, nor do they admit them into natural science otherwise than as a question whose truth may be discussed. (Ibid.)

Hypothesis may exist as a question, but is never foundational. Hypothesis is 'false conjecture', which is presented as dichotomous to the 'certain observations' of the empirical and experimental methods. Even more so, hypothesis is not just presented as uncertain, but as fictional, having the same status as dream or romance. Similarly, Cotes, in defending gravity from the accusation of being occult, contrasts 'those causes whose existence is very clearly demonstrated by observations' with 'those whose existence is occult, imagined, and not yet proved' (*Principia*, p. 392).

That said, Newton's science does not lack imagination and in his own practice, theory and experiment bleed into each other in a natural and symbiotic way, with ideas growing out of experiments and in turn suggesting further experiments which then support or falsify certain ideas. For example, Newton writes of a series of collision experiments in the *Principia*:

> the experiments just described work equally well with soft bodies and with hard ones, since surely they do not in any way depend on the condition of hardness. For if this rule is to be tested in bodies that are not perfectly hard, it will only be necessary to decrease the reflection

> in a fixed proportion to the quantity of elastic force. (*Principia*, p. 427)

As we saw with Boyle, there is an organic relationship between the experiment and the reasoning of it. Newton goes on to test his theory with softer bodies (balls of wool), concluding: 'in this manner the third law of motion — insofar as it relates to impacts and reflections — is proved by this theory, which plainly agrees with experiments' (ibid.). Theory and experiment combine to form a double pronged, rational argument that is more imaginative and better able to progress than bare empirical observation, but also more certain than purely hypothetical speculation.

Newton stresses the foundational role of empirical and experimental data to natural philosophy. However he does not idolize it, but rather acknowledges its limits, which he then tempers with reason. Although clearly expressing a belief in the capacity for human knowledge and understanding, Newton's epistemology, as Brian Copenhaver notes, also 'stressed the weakness of human cognition'.[5] In the General Scholium to the second edition of the *Principia*, Newton writes:

> We see only the shapes and colors of bodies, we hear only their sounds, we touch only their external surfaces, we smell only their odors, and we taste their flavours. But there is no direct sense and there are no indirect reflected actions by which we know innermost substances. (*Principia*, p. 942)

The intense sensuality of the first sentence dramatically contrasts the sensory data available to the natural philosopher with other inner qualities that he does not, and seemingly cannot, know. This echoes Hooke's frustration with the limited access to interiority and rather the multiplication of surfaces offered by the microscope, and the need expressed by Boyle to go beyond just superficial observations of things.

Newton also questions the certainty of deduction from empirical evidence. In a letter to Henry Oldenburg of 11 June 1672 discussing the debate with Hooke over the certainty of Newton's science of colours, Newton admits a contingency to experimental

[5] Brian P. Copenhaver, 'Jewish Theologies of Space in the Scientific Revolution: Henry More, Joseph Raphson, Isaac Newton and their Predecessors', *Annals of Science*, 37 (1980), 489–548 (p. 541).

and empirical principles that are the foundation of his mixed mathematics.[6] He writes:

> but who knows not that Optiques & many other Mathematicall Sciences depend as well on Physicall Principles as on Mathematicall Demonstrations: And the absolute certainty of a Science cannot exceed the certainty of its Principles.[7]

He goes on to describe the evidence for his propositions as being 'from *Experiments* & so but *Physicall:* Whence the Propositions themselves can be esteemed no more than *Physicall Principles* of a Science' (ibid.). The implication from the language used — 'but *Physicall*', 'can be esteemed no more than *Physicall Principles*' — being that physical, empirical, experimental principles are less certain than purely mathematical ones. Newton goes on in this letter to defend his science of colours, but it is important that empirical data is acknowledged to be contingent even at the same time as it is used as evidence.

Regardless of their contingency, Newton still prefers to base his philosophy on empirical and experimental principles as being more secure than the basis of the hypothetico-deductive method. As James Gleick points out, Newton never abandoned his reliance on sensation: his records of experiments and observations are replete with accounts of the taste, smell, and physical, sensory experience of phenomena.[8]

There are several ways in which Newton deals with the uncertainty of sensory data and the conclusions drawn from it. One way is to clearly demarcate those aspects of the workings of the universe he is making a claim for and then to allow room for those that he is not — that is, the undiscovered and the unknown — to also exist within that system. Often this means asserting the general rules exhibited by observed phenomena, but leaving their causes unexplained. In the *Principia*, Newton explains the mysterious phenomenon of action at a distance by gravity, but does not attempt to assert a cause for gravity itself:

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[6] Alan E. Shapiro, *Fits, Passions, and Paroxysms: Physics, Method, and Chemistry and Newton's Theories of Colored Bodies and Fits of Easy Reflection* (Cambridge: Cambridge University Press, 1993), p. 37.

[7] *The Correspondence of Isaac Newton*, ed. by H. W. Turnball, 7 vols (Cambridge: Cambridge University Press, 1959–1977), I (1959), 187.

[8] James Gleick, *Isaac Newton* (London: Fourth Estate, 2003), p. 104.

> For many things lead me to have a suspicion that all phenomena may depend on certain forces by which the particles of bodies, *by causes not yet known*, either are impelled toward one another and cohere in regular figures, or are repelled from one another and recede. (*Principia*, pp. 382–83, my emphasis.)

While Newton makes a claim for knowledge of how the universe operates at a physical level, he makes no such claim to know why this is so, or to know of its metaphysical workings.

Similarly, in the General Scholium, as part of his rejection of the feigning of hypotheses, Newton writes:

> It is enough that gravity really exists and acts according to the laws that we have set forth and is sufficient to explain the motions of the heavenly bodies and of our sea. (*Principia*, p. 943)

Observation and description of the laws of nature are sufficient for experimental philosophy, the implication being that valuable natural knowledge does not depend on a full knowledge of cause. Cotes similarly distinguishes the factual status of gravity from the factual status of the *cause* of gravity, and then expands this idea to include the unknown in the system itself.

> But will gravity be called an occult cause and be cast out of natural philosophy on the grounds that the cause of gravity itself is occult and not yet found? Let those who so believe take care lest they believe in an absurdity that, in the end, may overthrow the foundations of all philosophy. For causes generally proceed in a continuous chain from compound to more simple; when you reach the simplest cause, you will not be able to proceed any further. Therefore no mechanical explanation can be given for the simplest cause; for if it could, the cause would not yet be the simplest. (*Principia*, p. 392)

This suggests that there is, at the level of first cause, something fundamentally unknown — or at least something non-mechanical and therefore unknowable in terms of human natural philosophical knowledge — in the system itself.

As well as admitting to uncertainties, Newton — unlike the philosophers whom

Cotes criticizes for imagining the shape and size of unknown particles to be whatever they please — acknowledges the contingency of any assumptions made. For example, in a letter to Boyle of 28 February 1679 discussing the aether, Newton draws a figure expressing the manner in which saline and metal particles interact, depicting the particles as round (see Fig. 3.1), but notes that in it, ‘I have made the particles round, though they may be cubical, or of any other shape’ (*PW*, p. 6).

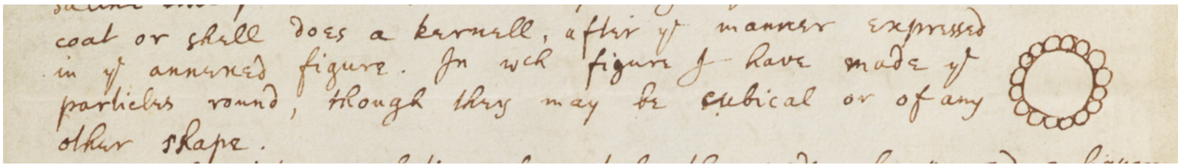
coat or shell does a kernell, after ye manner expressed in ye annexed figure. In wch figure I have made ye particles round, though they may be cubical or of any other shape.

Fig. 3.1. ‘Letter from Isaac Newton to Robert Boyle’, Cambridge University Library, Newton Papers, MS Add.9597/2/18, p. 63^{v} (cropped). Photo: © Cambridge University Library. Further reproduction prohibited without permission.

In the authorial preface to the *Principia*, Newton even suggests the contingency of his own methods, writing: ‘I hope that the principles set down here will shed some light on either this mode of philosophizing or some truer one’ (*Principia*, p. 383). There is room in Newton’s conception of natural philosophy for update and revision of both facts and approaches. He continues:

> I earnestly ask that everything be read with an open mind and that the defects in a subject so difficult may be not so much reprehended as investigated, and kindly supplemented, by new endeavours of my readers. (Ibid.)

For all of his seclusion and anti-social practices, Newton — like Boyle and Hooke — had epistemological principles that conceived of knowledge as a collective endeavor and he was, in theory, open to his work being treated as contingent and to be developed by other practitioners.

As well as contingency, the other significant aspect of Newton’s method and epistemology is the idea of consistency. Newton was searching for underlying principles, for the general rules by which nature operates that can be established from observable and experimental phenomena. This not only tells us about the task he was attempting, but also reveals an important assumption or guiding principle to his work:

that of the logical consistency of nature. As well as guiding his agenda, this assumption serves as an epistemological tool in Newton's philosophical arsenal, legitimizing his claims to be uncovering truths despite the limits of human knowledge and cognition, and allowing him to develop a methodology or epistemological approach by which he can develop knowledge beyond what is provable by direct experience, but without relying on hypotheses. In the 'Rules for the Study of Natural Philosophy' laid out in the *Principia*, Newton writes:

> For the qualities of bodies can be known only through experiments; and therefore qualities that square with experiments universally are to be regarded as universal qualities; and qualities that cannot be diminished cannot be taken away from bodies. Certainly idle fancies ought not to be fabricated recklessly against the evidence of experiments, nor should we depart from the analogy of nature, since nature is always simple and ever consonant with itself. The extension of bodies is known to us only through our senses, and yet there are bodies beyond the range of these senses; but because extension is found in all sensible bodies, it is ascribed to all bodies universally. (*Principia*, p. 795)

Again, Newton rejects hypothesis ('idle fancies') and asserts experimental evidence as the basis for philosophical knowledge, but he also adds a logical step of universal applicability based on the idea that, 'nature is always simple and ever consonant with itself'.

Cotes's preface also describes this principle of inference from an assumption of consistency, giving examples of events happening at different earthly locations:

> The preceding conclusions are based upon an axiom which is accepted by every philosopher, namely, that effects of the same kind — that is, effects whose known properties are the same — have the same causes, and their properties which are not yet known are also the same. For if gravity is the cause of the fall of a stone in Europe, who can doubt that in America the cause of the fall is the same? (*Principia*, p. 391)

There is a fascinating chicken and egg quality to his argument. Cotes continues:

> All philosophy is based on this rule, inasmuch as, if it is taken away, there is then nothing we can affirm about things universally. The constitution of individual things can be found by observations and experiments; and proceeding from there, it is only by this rule that we make judgments about the nature of things universally. (Ibid.)

Consistency is assumed, not only because it is a reasonable assumption, but also because it is a necessary one in order for man to be able to conduct natural philosophy.

Newton summarizes his principle of generalization by induction in the General Scholium, after the famous assertion, 'I do not feign hypotheses'. He writes:

> For whatever is not deduced from the phenomena must be called a hypothesis; and hypotheses, whether metaphysical or physical, based on occult qualities or mechanical, have no place in experimental philosophy. In experimental philosophy, propositions are deduced from the phenomena and are made general by induction. The impenetrability, mobility, and impetus of bodies, and the laws of motion and the law of gravity have been found by this method. (*Principia*, p. 943)

Induction is distinguished from hypothesis and presented as a stable basis for formulating the laws of nature. Similarly, while this method does not allow Newton to make calculations on or draw conclusions about hidden metaphysical properties — such as the 'innermost substances' mentioned in the General Scholium — induction or inference from the known does allow him to do so for physical bodies beyond the range of sensory perception, including qualities of distant bodies such as the planets and comets, invisible interactions such as gravity and other forces, or subvisible phenomena such as atoms. In the unpublished draft 'Conclusio' to the *Principia*, written in 1686/87, Newton infers a micro world from the macro one and assumes a physical consistency between them, sharing his suspicion that there are 'lesser forces, as yet unobserved, of insensible particles' and stating that 'whatever reasoning holds for greater motions, should hold for lesser ones as well'.[9]

Newton outlines several rules for the determining of causes and gathering of

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[9] *Unpublished Scientific Papers of Isaac Newton*, ed. and trans. by A. Rupert Hall and Marie Boas Hall (Cambridge: Cambridge University Press, 1962), p. 333.

propositions. These rules are summarized:

> Rule 1: *No more causes of natural things should be admitted than are both true and sufficient to explain their phenomena.* […]
> Rule 2: *Therefore, the causes assigned to natural effects of the same kind must be, so far as possible, the same.* […]
> Rule 3: *Those qualities of bodies that cannot be intended and remitted and that belong to all bodies on which experiments can be made should be taken as qualities of all bodies universally*. […]
> Rule 4: *In experimental philosophy, propositions gathered from phenomena by induction should be considered either exactly or very nearly true notwithstanding any contrary hypotheses, until yet other phenomena make such propositions either more exact or liable to exceptions.* (*Principia*, pp. 794–96)

Rule 1 offers a safeguard to the certainty of what is admitted as a cause in its principle of a minimal limit. It follows from this in Rule 2 that there should be typological similarity between causes. Rule 3 states that qualities of bodies should be treated as universal, and Rule 4 expresses that principles known through experiments should be treated as universal (albeit contingently so). What distinguishes these practices from the feigning of hypotheses as foundational principles so criticized by Newton elsewhere, is that for Newton the step of universal applicability is not used to assert hypothesized truths as ontological realities, but rather — as the fourth rule in particular demonstrates — as contingent propositions to be treated as true in order to enable natural philosophical working and the further development of knowledge. It is a methodological and epistemological principle, not a metaphysical one.

In the discussion under the third rule, Newton provides a good example of his practice:

> That all bodies are impenetrable we gather not by reason but by our senses. We find those bodies that we handle to be impenetrable, and hence we conclude that impenetrability is a property of all bodies universally. That all bodies are movable and persevere in motion or in rest by means of certain forces (which we call forces of inertia) we infer from finding these properties in the bodies that we have seen. The extension, hardness, impenetrability, mobility, and force of inertia of the whole arise from the extensions, hardness,

> impenetrability, mobility, and force of inertia of each of the parts; and thus we conclude that every one of the least parts of all bodies is extended, hard, impenetrable, movable, and endowed with a force of inertia. And this is the foundation of all natural philosophy. (*Principia*, pp. 795–96)

Knowledge about bodies that aren't tested — including their 'least parts', which might not be possible to experiment on — is garnered by inference from what is learned of those that are. It is possible to interpret Newton's statement, 'this is the foundation of all natural philosophy', in two ways: first, that universal applicability is the foundation of natural philosophy, and second, that these specific properties of bodies, which are assumed to be universal, are the foundation of natural philosophy. Certainly for Newton's universe, the latter is required in order for it to work as a whole interrelated system, but both ideas fit as foundational to Newton's physics and philosophy. Neither are they unrelated. Newton's work — which marks the turn in physics from kinematics to dynamics — is all about movement, about tracing the paths of bodies, the interactions of forces, and rates of change. The consistency of natural phenomena *and* the consistent qualities of bodies listed above are both necessary for his physics. Thus, there is a sense in which the assumption of consistency is spatial as it is at heart about relations within space. More specifically, given the mathematical nature of Newton's approach, a key concern is with measuring and thus quantifying such relations, and as such we find that in Newton's work epistemology is intimately connected with the metaphysics of space and time.

There is also a connection in Newton's work between epistemology and God with Newton relating his epistemological anxiety about the limits of sensory experience — and thus natural philosophical knowledge — to the limits of man's spiritual knowledge and capacity for knowledge of God. The passage from the General Scholium, lamenting that 'there is no direct sense and there are no indirect reflected actions by which we know innermost substances', continues: 'much less do we have an idea of the substance of God' (*Principia*, p. 942). The vivid detailing of what we do know of substances by each of the five senses ('we see only the shapes and colors of bodies, we hear only their sounds' etc.) seems an inverted echo of I Corinthians 2. 9, 'Eye hath not seen, nor ear heard [...] the things which God hath prepared'. Newton's description, like descriptions of God in the apophatic tradition, casts what we do sense in a negative frame and draws attention to what we don't see, hear, touch, smell, or taste — that is, innermost substances and the substance of God. And yet, at the same time as acknowledging the unknowability of God, Newton asserts that man is not without hope: 'for all discourse about God is derived through a certain similitude from things human, which while not perfect is nevertheless a similitude of some kind' (*Principia*, pp. 942–43). This contingent inference shares a similar methodological and philosophical position to Newton's use of the assumption of the logical consistency of nature to infer from sensory data the characteristics of bodies beyond the range of the senses.

Newton's technique of leaving room for the unknown (and particularly for unknown causes) in his system of the universe, naturally allows room for God. In the *Principia* he writes of the cause of gravity as 'not yet known'. In a letter to Bentley on the same subject, he elaborates further:

> Gravity must be caused by an agent acting constantly according to certain laws, but whether this agent be material or immaterial is a question I have left to the consideration of my readers.[10]

Newton still declines to name a cause, but leaves room specifically for the possibility of an immaterial agent. When he writes about first causes, Newton makes the connection between religion and natural philosophy clear. He outlines 'the main business of natural philosophy' in his 'Queries' to the *Opticks*, writing about not feigning hypotheses, but also about 'deduc[ing] causes from effects, till we come to the very first cause, which certainly is not mechanical' (quoted above). The inclusion of a non-mechanical cause unites the purpose of natural philosophy to the search for knowledge of God through the chain of causality; the understanding of physical causality will ultimately result in the understanding of the first cause, that is, God. This is also connected to Newton's principles of generalization and abstraction through the idea of simplification as one goes back through the chain of causes to the simplest cause (which cannot be mechanical) as described in Cotes's preface. This fits Newton's ideas about contingency and admitting unknown causes into natural philosophy, and as we see in the 'Account of the Book Entitled *Commercium Epistolicum*' (1715), Newton suggests that treating unknown causes — including laws which come from God — as miraculous or occult

[10] 25 Feb 1693, in *Correspondence*, III (1961), 254.

rather than part of the system, is rather throwing the baby out with the bath water.

> The one [Newton] teaches that philosophers are to argue from phenomena and experiments to the causes thereof, and thence to the causes of those causes, and so on till we come to the first cause: the other [Leibniz] that all actions of the first cause are miracles, and all the laws impressed on nature by the will of God are perpetual miracles and occult qualities, and therefore not to be considered in philosophy. But must the constant and universal laws of nature, if derived from the power of God or the action of a cause not yet known to us, be called miracles and occult qualities, that is to say, wonders and absurdities? (*PW*, p. 125)

First causes might be simple and non-mechanical, but there is an assumption that they are consistent and comprehensible rather than absurd. Newton believes in the all-powerful will of God, but assumes a consistency to the application of this will. According to Newton, God is a part of his own system.

Newton finds precedent for his unity of natural philosophy and theology in the practice of ancient priests:

> So then twas one designe of the first institution of the true religion to propose to mankind by the frame of the ancient Temples, the study of the frame of the world as the true Temple of the great God they worshipped. And thence it was that the Priests anciently were above other men well skilled in the knowledge of the true frame of Nature & accounted it a great part of their Theology. [...] So then the first religion was the most rational of all others till the nations corrupted it. ffor there is no way (without revelation) to come to the knowledge of a Deity but by the frame of Nature.[11]

Natural philosophy and theology are related to one another by both method and purpose; as Newton writes in the General Scholium, ‘to treat of God from phenomena is

[11] Isaac Newton, *Draft chapters of a treatise on the origin of religion and its corruption*, Yahuda Ms. 41, <http://www.newtonproject.sussex.ac.uk/view/texts/normalized/THEM00077> [accessed 8 May 2013] (f. 7^r).

certainly a part of natural philosophy' (*Principia*, p. 943).[12] It is telling that Newton uses the same phrase, 'the frame of Nature' in both this theological text and in his natural philosophical writings. As he writes in the Yahuda manuscript, the true frame of Nature was considered by the ancient priests to be 'a great part of their Theology'. In a letter to Richard Bentley, Newton offers another suggestion that for him the structures of Christian faith are entwined with human reason and empirical evidence, claiming: 'When I wrote my treatise about our Systeme I had an eye upon such Principles as might work wth [*sic*] considering men, for the beleife of a Deity'.[13] We see this illustrated in Newton's arguments from design for the existence of God and his hand in creation in his letters to Bentley and also in the General Scholium: 'This most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being' (*Principia*, p. 940).

Newton, in the 'Queries' to the *Opticks*, also writes about the enlarging of moral philosophy by the act of perfecting natural philosophy and thus increasing our knowledge of the first cause:

> For so far as we can know by natural philosophy what is the first cause, what power he has over us, and what benefits we receive from him, so far our duty towards him, as well as towards one another, will appear to us by the light of nature. And no doubt, if the worship of false gods had not blinded the heathen, their moral philosophy would have gone farther […], they would have taught us to worship our true author and benefactor, as their ancestors did under the government of Noah and his sons before they corrupted themselves. (*PW*, p. 140)

Newton speaks of redeeming the corruption of man by means of natural philosophical learning. Intriguingly, the corruption Newton is thinking of is not original sin, but the *confusio linguarum* that occurred in the days of Noah and his sons. This does not carry the same sense of irreversible degradation of the human faculties, which is often associated with the Fall. As with the similitude between God and man posited in the *Principia*, there is a sense of the possibility for and the capacity of human knowledge. Furthermore, this is associated with the practice of natural philosophy.

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[12] NB 'natural philosophy', quoted here from the third edition, read 'experimental philosophy' in the second.

[13] *Correspondence*, III, 233.

As we saw in Hooke and Boyle, Newton acknowledges a tension between the limits and possibilities of human knowledge. However, more than the others —and certainly more so than the nescient Boyle — there is a confidence to Newton's epistemology, which assumes that the patterns found in the human experience of creation reflect a consistency in the chain of its causation, and are to be the basis of our understanding of both creation and cause. There is also a practicality to Newton's method; the assumption of consistency and the admitting of contingent knowledge and treating it as fact, whilst still acknowledging its contingency, allows for the development of knowledge and the formulation and understanding of universal laws.

Absolute and Relative Space

In order to be understood, Newtonian dynamics requires frames of reference. Bodies in motion must be moving relative to something in order to be measurable or perceivable as such. Between the sections containing the definitions and the laws of the *Principia* sits Newton's famous scholium on absolute space and time, where he makes a distinction between absolute and relative versions of time, space, place, and motion. With regard to space, Newton writes:

> Absolute space, of its own nature without reference to anything external, always remains homogeneous and immovable. Relative space is any movable measure or dimension of this absolute space; such a measure or dimension is determined by our senses from the situation of the space with respect to bodies and is popularly used for immovable space, as in the case of space under the earth or in the air or in the heavens, where the dimension is determined from the situation of the space with respect to the earth. (*Principia*, pp. 408–09)

Newton describes two types of space: relative space, which can be in motion and which we determine with our senses by means of reference to discernible, physical bodies; and a mathematical, absolute space, which we do not perceive sensually but which acts as a fixed backdrop or frame to relative space.

Absolute and relative time are conceived in a similar way:

> Absolute, true and mathematical time, in and of itself and of its own nature, without reference to anything external, flows uniformly and by another name is called duration. Relative, apparent, and common time is any sensible and external measure (precise or imprecise) of duration by means of motion; such a measure — for example, an hour, a day, a month, a year — is commonly used instead of true time. (*Principia*, p. 408)

Like relative space, relative time is sensible and measured externally. However, the presentation is much less static than that of space. Relative time is measured by motion, and absolute time — while still having that sense of being the backdrop of all times out of which relative time (a sensible and external measure of duration or absolute time) is experienced — also has its own sense of movement, albeit without reference to anything external as it 'flows uniformly'. Absolute time is both backdrop and a state of uniform progression.

Of the more minor terms, place is defined as 'the part of space that a body occupies' which is absolute or relative 'depending on the space', and absolute motion is 'the change of position of a body from one absolute place to another', while relative motion is 'change of position from one relative place to another' (*Principia*, p. 409).

As Julian Barbour describes, the whole corpus of Newton's work on dynamics was based on the concept, taken from Descartes, of uniform rectilinear motion of undisturbed bodies. Barbour points out that, 'The main question at issue is: uniform and rectilinear with respect to what?' and shows that for Newton (as for Galileo and pre-Inquisition Descartes) the answer is that it is with respect to absolute space, and that if such a space is granted, the formulation of the law of inertia is unproblematic.[14] Another important aspect of Newtonian dynamics is, as Howard Stein has shown, its connection not just to space, but also to space-time.[15] Even duration is measured 'by means of motion'. This four-dimensionality is crucial for the descriptions of bodies in motion and rest, but relies on the structure of absolute space in order to be understood. As Michael

[14] Julian Barbour, *Absolute or Relative Motion: A Study from a Machian Point of View of the Discovery and the Structure of Dynamical Theories*, *Volume 1*, *The Discovery of Dynamics* (Cambridge: Cambridge University Press, 1989), p. 610.

[15] Stein, p. 176.

Friedman describes in the parlance of modern physics, Newtonian physics operates as a 'four-dimensional differentiable manifold.'[16] If we consider any two points within this manifold, there is a notion of the temporal interval between them that is defined independently of the spatial coordinate system. Similarly, for any single point in the manifold, there is a notion of the set of all other points simultaneous with it, again, defined independently of the coordinate system. These simultaneity sets are called 'planes of absolute simultaneity' and each three-dimensional plane of absolute simultaneity is a Euclidean three-space.[17] These planes then need to be combined to understand the full manifold. Friedman writes:

> We have a separate Euclidean geometry on each instantaneous three-space, but we have so far defined no spatial relations at all between points on different planes of simultaneity. To combine our different instantaneous three-spaces into one big 'enduring' three-space we need an additional geometrical structure. The additional structure we need is *absolute space*: a relation of occurring-at-the-same-place defined between arbitrary points in *M* [i.e. the manifold] (not just between pairs of points in the same plane of simultaneity). We can introduce such a relation by means of a *rigging* of space-time: a family of non-intersecting geodesics that 'penetrates' each plane of simultaneity.[18]

With this structure in mind, we have a stable backdrop against which we can imagine and plot movement and rest in any or all of the four dimensions (see Fig. 3.2).

[16] Michael Friedman, *Foundations of Space-Time Theories: Relativistic Physics and Philosophy of Science* (Princeton: Princeton University Press, 1983), p. 71.

[17] Friedman, pp. 72–73.

[18] Friedman, p. 74.

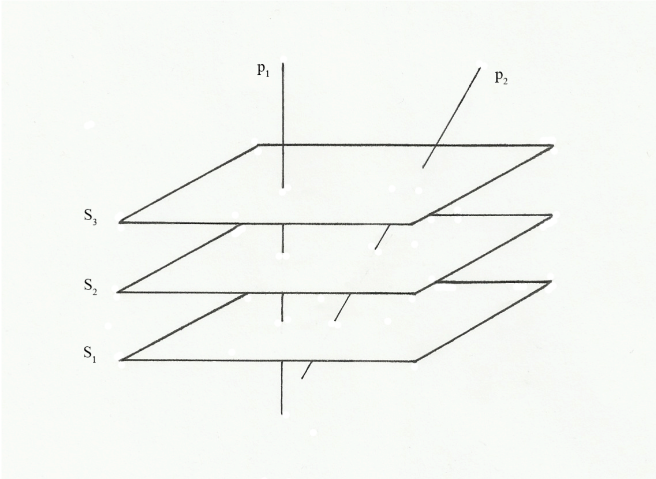

Fig. 3.2. Diagram showing the manifold *M*, where S_1, S_2, and S_3 are planes of absolute simultaneity, p_1 expresses a relation of occurring-at-the-same-place over time (e.g. the trajectory of a particle at rest), and p_2 is the trajectory of a particle moving in uniform motion.

As Robert DiSalle summarizes:

> Absolute space is that with respect to which the velocity of every body is its true velocity. It requires, therefore, that we should be able to say of any thing whether it occupies the same place from moment to moment. In other words, it implies that there is a set of trajectories in space-time that may be distinguished as the histories of particles that remain at rest.[19]

Such a trajectory of a particle at rest through time would follow the path of Friedman's rigging, of one of the geodesics penetrating the planes of simultaneity. The structure described by Friedman fits with both Newton's description of absolute space and time, and his use of these concepts in his physics.

In Newton's descriptions of space and time, the ability to measure and perceive are key factors that distinguish the relative from the absolute. Relative space is 'any movable measure or dimension of this absolute space' and we are told that 'such a measure or dimension is determined by our senses'. Similarly, relative time is, 'any sensible and external measure [...] of duration'. In a way measurement and sensory perception are almost tautologous: if we can perceive a quantity by means of the senses then we can understand it in relation to other sensory experiences and thus measure it.

[19] DiSalle, pp. 25–26.

However, Newton's pedantry emphasizes the methodological and epistemological importance of sensory perception: in order to make natural philosophy mathematical, phenomena must be quantifiable, that is, measurable; such measurement can only come to us from the relative world of human perception — we cannot deal directly with abstractions.

In the descriptions of both absolute space and absolute time, Newton uses the phrase 'of its own nature, without reference to anything external'. This lack of external reference emphasizes both the absoluteness of these structures in and of themselves, but also our lack of access to them. As such, space as an object of natural philosophical consideration is epistemologically fraught. Relative space can only be perceived 'from the situation of the space with respect to bodies' and so, like the invisible air, its observation and measurement relies on inference from the observation of other things. Absolute space is even more problematic, being seemingly unknowable by the senses. Newton writes: 'these parts of space cannot be seen and cannot be distinguished from one another by our senses' (*Principia*, p. 410).

These tensions are compounded by the fact that Newton aligns the inaccessible absolute with true and mathematical quantities, and the accessible relative with apparent and common ones, the oppositional presentation of these descriptions encouraging the idea that the relative is inferior. Relative quantities are held to be tainted with preconceptions arising from their derivation from objects of sense perception:

> Although time, space, place, and motion are very familiar to everyone, it must be noted that these quantities are popularly conceived solely with reference to the objects of sense perception. And this is the source of certain preconceptions; to eliminate them it is useful to distinguish these quantities into absolute and relative, true and apparent, mathematical and common. (*Principia*, p. 408)

The implication is that the abstract absolute notions of space, time, place, and motion offer truer quantities than their relative counterparts, and indeed do so because they are not dependent on sense perception. We can see how this may be so in Newton's comparison of absolute and relative space:

> Absolute and relative space are the same in species and in magnitude, but they do not always remain the same numerically. For example, if

> the earth moves, the space of our air, which in a relative sense and with respect to the earth always remains the same, will now be one part of the absolute space into which the air passes, not another part of it, and thus will be changing continually in an absolute sense. (*Principia*, p. 409)

Even if the earth is moving, then in a relative sense the space of the air with respect to the earth remains the same: it appears still. However, in an absolute sense, with respect to a backdrop of fixed space, it moves. Our intuitive perceptions of stillness and motion are thus only relative or apparent. They are not truths, nor are they mathematically sufficient.

And yet, in the passage quoted above starting, 'Although time, space, place, and motion are very familiar', we see that Newton believes it is possible to eliminate the preconceptions of sense perception. He proposes to do this by the very act of distinction between absolute and relative itself. The act of recognizing the contingency of relative space allows such compromises to be used in order to further knowledge. It also prevents calculations on relative data from being a naïve final resting place for enquiry; the fact that we can imagine absolute space — even if we can't perceive it — allows us to make adjustments to relative data in a layer of abstract, mathematical thought subsequently imposed on what is perceived relatively. Commentators usually focus on the distinction between relative and absolute space and time, but Newton's technique actually relies on the distinction *and recombination* of the two. Newton distinguishes between our absolute and relative conceptions of space along lines evocative of the distinctions between the activities of fit and unfit readers in Milton, the distinction between 'Mathematical' and 'common' (*vulgares*) qualities possibly implying a distinction between mathematical and common interpreters (although perhaps with less pejorative connotation than we might read in 'common', as *vulgus* is used in the previous sentence in the sense of 'familiar').[20] The addition of reading skills (skills of interpretation) rooted in self-knowledge (an awareness of relativity) to what is perceived sensually, is required in order to avoid being an unfit interpreter reading only the

[20] Latin text from Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (London: Joseph Streater, 1687), p. 5.

'apparent' or 'common' qualities, and to perceive more truly.[21] This takes the form of recontextualizing relative space in terms of an understanding of absolute space to make it mathematical and rational. Newton writes that relative understandings are 'not inappropriate in ordinary human affairs, although in philosophy abstraction from the senses is required' (*Principia*, p. 411). Taking into consideration the wider context of Newton's use of empiricism, experiment, measurement, and observation, the importance of abstraction being '*from* the senses' (*a sensibus*) is apparent; this abstraction is not a rejection of the sensory, but a development of it — Newton uses the experience of relative understandings of space to step beyond to something abstract.[22] Similarly, Newton's definition of the popular conception being '*solely* [*non aliter*] with reference to the objects of sense perception' (my emphasis) implies that the error is not the reference to sensory objects in and of itself, but the lack of some additional reference to eliminate preconception and thus make the data more robust.[23] Like Boyle's experimental spaces, the concept of absolute space exerts a form of control and mensurability over the motions or interactions in question, which allows Newton to work at a less superficial level. Newton captures this sense of mixed or applied mathematics in his description of the *Principia* as a work of '*rational mechanics*', describing mechanics as being distinct from geometry by means of its lack of exactness (*Principia*, pp. 381–82).

One of the major criticisms of Newton's theory of absolute and relative space stems from the epistemological difficulty of absolute space. Contemporary philosophers — including Leibniz, Huygens, and Berkeley — presumed that Newton's absolute space was posited as a metaphysical theory and so objected to its unobservable and thus hypothetical nature. In the wake of Mach, Einstein, and twentieth-century relativity, many historians treated Newton's absolutism with contempt.[24] However, Stein neutralizes some of the apparent problems of absolute space by recontextualizing the

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[21] See Sharon Achinstein, 'Milton and the Fit Reader', in *British Literature 1640–1789: A Critical Reader*, ed. by Robert DeMaria, Jr (Oxford: Blackwell, 1999), pp. 40–68 (pp. 48–50, 66).

[22] *Principia* (1687), p. 7.

[23] *Principia* (1687), p. 5.

[24] For example, E. A. Burtt describes Newton's idea as an 'error', and writes that, 'the very nature of absolute space negates the possibility of its having any assignable significance'. See E. A. Burtt, *The Metaphysical Foundation of Modern Physical Science*, rev. edn (London: Routledge & Keegan Paul, 1932), pp. 256, 255.

idea, not as a physical proposition but as an epistemological construct. Absolute space is not a proposed theory of the arrangement or nature of matter, but a piece of mental apparatus necessary for constructing and thinking about Newton's dynamical laws, which need a fixed backdrop against which moving bodies can be understood. Stein concludes that 'the principles of dynamics [...] distinctly require a view of motion and therefore of place and space that cannot be explicated in terms simply of the geometrical relations among bodies'.[25] Similarly, DiSalle argues that Newton was not trying to answer the presumed question of whether space, time, and motion were absolute or relative. Newton's aim rather, was to 'define' absolute space, time, and motion, 'to exhibit empirical criteria for applying the concepts, and to reveal the roles that they play in *solving the problems* of mechanics.'[26] Stein and DiSalle are in harmony with Newton's suggestion that absolute space is *useful* in eliminating preconceptions; this is not about space but about thinking about space.

Newton's understanding of natural philosophy as contingent and his view of empiricism as foundational and yet limited are compatible with the thesis of absolute space as an epistemological construct. Similarly, the notion that the principles set down in the *Principia* are but one 'mode of philosophizing' — and a contingent one at that — suggests that Newton offers but one method of reading nature, not a definitive portrait of its reality.

This practical approach to definition and the language in which Newton conducts natural philosophy can also be seen at a more local level throughout his works. For example, just before the scholium on space and time, his definition of 'The motive quantity of centripetal force' includes phrases such as 'so to speak' (*ut ita dicam*), 'for the sake of brevity' (*brevitatis gratia*), and 'for the sake of differentiation' (*distinctionis gratia*), emphasizing the need to accommodate physics to a suitable form of language in order to understand and discuss it (*Principia*, p. 407).[27] Shortly after, Newton continues:

> Moreover, I use interchangeably and indiscriminately words signifying attraction, impulse, or any sort of propensity toward a center, considering these forces not from a physical but only from a mathematical point of view. Therefore, let the reader beware of

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[25] Stein, p. 197.

[26] DiSalle, p. 17, my emphasis.

[27] See also *Principia* (1687), pp. 3–4.

> thinking that by words of this kind I am anywhere defining a species or mode of action or a physical cause or reason, or that I am attributing forces in a true and physical sense to centers (which are mathematical points) if I happen to say that centers attract or that centers have forces. (*Principia*, p. 408)

For Newton, the act of description is intimately connected with the act of mathematical abstraction, which he makes a point of separating from a definition of physical truth. This association supports the idea that these abstract structures are epistemological rather than metaphysical or ontological.

As numerous critics have observed, Newton's distinction between absolute and relative space was a reaction to the failures of Cartesian relationalism, which lacked consistency and coherence.[28] This also adds support to the idea that absolute space is epistemological rather than ontological. This anti-Cartesian thread is apparent in his published works, including the *Principia*, but is most explicitly found in the manuscript treatise *De Gravitatione*.[29] Newton complains:

> When a certain motion is finished it is impossible, according to Descartes, to assign a place in which the body was at the beginning of the motion; it cannot be said from where the body moved. And the reason is that according to Descartes, the place cannot be defined or assigned except with respect to the position of the surrounding bodies, and after the completion of some motion the position of the surrounding bodies no longer stays the same as it was before. (*PW*, p. 19)

The problem is not with the nature of motion through space, it is with the fact that motion cannot be calculated or understood mathematically using Descartes's relative version of space and place. This is particularly problematic for the concept of velocity, which is vectorial (i.e. it requires both magnitude and direction). According to Newton, this inability to describe motion speaks of the need for absolute space:

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[28] DiSalle, 2006, pp. 16–19, 36–37; Barbour, pp. 604–05; Curtis Wilson, 'The Newtonian Achievement in Astronomy', in *Planetary Astronomy from the Renaissance to the Rise of Astrophysics: Part A: Tycho Brahe to Newton*, ed. by René Taton and Curtis Wilson (Cambridge: Cambridge University Press, 1989), pp. 233–74 (p. 235).

[29] Probably written before 1685, see *PW*, 'introduction', p. xviii.

> Cartesian motion is not motion, for it has no velocity, no determination, and there is no space or distance traversed by it. So it is necessary that the definition of places, and hence of local motion, be referred to some motionless being such as extension alone or space in so far as it is seen to be truly distinct from bodies. (*PW*, pp. 20–21)

Space that is distinct from bodies, i.e. without reference to anything external, is absolute space. In contrast to Descartes's relational space, Newton's structure of absolute and four-dimensional space-time does allow for the adequate description of motion and does not contradict the laws of motion.

The need for a spacio-temporal structure that can adequately accommodate the motion and rest of bodies can be felt in the restrictive nature of the static, two-dimensional diagrams with which Newton seeks to represent paths of motion and rates of change. Newton distinguishes in his notes between geometric and what he calls 'mechanicall lines', these latter mapping the motion of a point, or two such motions compounded (i.e. a vector).[30] The reader must understand the mechanical line in the static diagram as tracing a path over time. Rates of change require a further mental process; as Gleick describes, they are 'an abstraction of an abstraction'.[31] This applies visually as well: the curves representing rate of change don't even map the trace of a path over time, but rather the acceleration of the movement. Gleick notes that while Newton's diagrams look static they actually 'depicted processes of dynamic change', again quoting the accompanying descriptions:

> His lemmas spoke of quantities that *constantly tend to equality* or *diminish indefinitely*; of areas that *simultaneously approach* and *ultimately vanish*; of *momentary increments* and *ultimate ratios* and *curvilinear limits.* He drew lines and triangles that looked finite but were meant to be on the point of vanishing.[32]

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[30] *The Mathematical Papers of Isaac Newton*, ed. by D. T. Whiteside, 8 vols (Cambridge: Cambridge University Press, 1967–1980), I (1967), 377.

[31] Gleick, p. 46.

[32] Ibid.

This creates a dependence in the diagrams on the accompanying text. Gleick observes that while 'the diagrams appeared to represent space' on reading the accompanying descriptions, 'time kept creeping in'.[33]

The diagram offers a map and the text instructs the reader in how to read it so that he or she can trace the movements or imagine the passage of time accordingly and bring the motion to life in the mind. For example in the text accompanying the diagram (see Fig. 3.3) in Proposition 34, Problem 14 of Book III, '*To find the hourly variation of the inclination of the lunar orbit to the plane of the ecliptic*', the reader is asked to let *m*T*l* represent 'the momentaneous motion' of the nodes N and *n*. The angle PG*p* (where P is the place of the moon in its orbit, and *p* the projection of that place on the plane of the ecliptic) 'will be the inclination of the moon's orbit to the plane of the ecliptic when the moon is in P', and the angle P*gp* 'will be the inclination of the same orbit after a moment of time has been completed'. Therefore the angle GP*g* 'will be the momentaneous variation of the inclination' (*Principia*, p. 864).

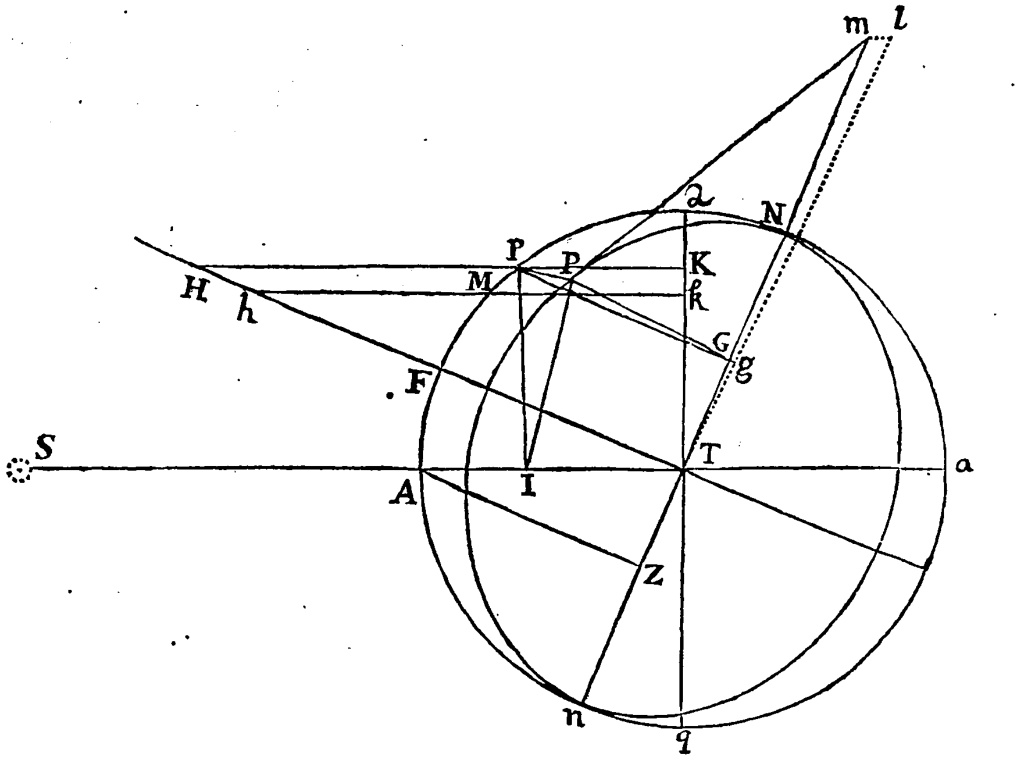

Fig. 3.3. Isaac Newton, *Philosophiae naturalis principia mathematica* (London, 1687), p. 457 (cropped). Photo: © Cambridge University Library. Image published with permission of ProQuest. Further reproduction is prohibited without permission.

[33] Gleick, p. 134.

In *De Gravitatione*, Newton connects the idea of delineation of figures with a somewhat more metaphysical discussion, but in a way that frames the practice as epistemological. In discussing the ability to distinguish space into parts by mathematical surfaces, lines, and points, he asserts:

> And hence there are everywhere all kinds of figures, everywhere spheres, cubes, triangles, straight lines, everywhere circular, elliptical, parabolical, and all other kinds of figures, and those of all shapes and sizes, even though they are not disclosed to sight. For the delineation of any material figure is not a new production of that figure with respect to space, but only a corporeal representation of it, so that what was formerly insensible in space now appears before the senses. (*PW*, pp. 22–23)

Delineation is an act of making visible, of understanding a structure in a certain way, not of bringing into being. In an explanatory analogy of adding colour to water to make shapes appear in it, Newton writes: ‘However, if the color were introduced, it would not constitute material shapes, but only cause them to be visible’ (*PW*, p. 23).

Newton, in the scholium on space and time, addresses the difficulty in calculating true motions that the imperceptibility of absolute space occasions:

> It is certainly very difficult to find out the true motions of individual bodies and actually to differentiate them from apparent motions, because the parts of that immovable space in which the bodies truly move make no impression on the senses. Nevertheless, the case is not utterly hopeless. For it is possible to draw evidence partly from apparent motions, which are the differences between the true motions, and partly from the forces that are the causes and effects of the true motions. (*Principia*, p. 414)

First of all it is worthwhile to note that the importance of being able to perceive or not perceive absolute space is not because of a desire to know about absolute space in and of itself, but rather because it is important for working out the true motions of bodies against its backdrop. Newton is also under no illusions about the need to recourse to the relative in order to gather evidence and thus perform his calculations. However, his awareness of the status of this data as merely apparent, allows him to see the need to mentally adjust and calculate for that. Newton then goes on to describe his famous thought experiment — the example of two balls attached by a chord rotating around a common centre of gravity — showing that it is possible to determine data about true motion ('the quality and direction of the circular motion') from the evidence of apparent motions (the tension in the chord and the change in tension under difference forces), even 'where nothing external and sensible existed with which the balls could be compared' (ibid.). Indeed 'how to determine true motions from their causes, effects, and apparent differences, and, conversely, of how to determine from motions whether true or apparent, their causes and effects', is the stated purpose of the work (*Principia*, p. 415).

In understanding the connection between absolute and relative space, the notion of place is significant. In Newton's criticism of Descartes in *De Gravitatione*, the inability to assign place makes a nonsense of the effort to define and understand or calculate motion mathematically. As Edward Casey describes, a characteristic of early modern thinkers is a disdain for the *genius loci* and indifference to the specialness of place intrinsic to Aristotelian thought. However, even with its reduced scope, place still has an important power in its ability to be the limit for something else.[34] Unlike the metaphysical scope of Aristotelian place, this redefined power or role is epistemological.

In Newton we see just this. Place is important for locating and thus measuring and defining space, or more specifically, bodies in space and their movement through space, but there is no special quality or identity reserved for each part of space, other than its geometric location. Newton writes in *De Gravitatione*:

> The parts of duration and space are understood to be the same as they really are only because of their mutual order and position; nor do they have any principle of individuation apart from that order and position, which consequently cannot be altered. (*PW*, p. 25)

Place is abstract and is defined by its order and position, it does not itself determine order as it did in the Aristotelian system. As Casey describes, Newton subsumes place under space and as a part of space, so it has no being or identity other than that of space

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[34] Edward S. Casey, *The Fate of Place: A Philosophical History* (Berkeley: University of California Press, 1998), pp. 133–34.

itself. It is in this sense, pure construct. At the same time, Newton also collapses place into body. Together, these two moves deny autonomy to place.[35] We see them cohere in Newton's definition: 'Place is the part of space that a body occupies' (*Principia*, p. 409).

The idea that place and order are intrinsically linked and that this is a part of understanding unmovable (that is, absolute) space is also found in the *Principia*:

> Just as the order of the parts of time is unchangeable, so, too, is the order of the parts of space. Let the parts of space move from their places, and they will move (so to speak) from themselves. For times and spaces are, as it were, the places of themselves and of all things. All things are placed in time with reference to order of succession and in space with reference to order of position. It is the essence of spaces to be places, and for primary places to move is absurd. They are therefore absolute places, and it is only changes of position from these places that are absolute motions. (*Principia*, p. 410)

The identity of parts of duration and space is purely one of order, of spatial or temporal location, and this is the notion of place. In the cases of Hooke and Boyle, ordering was most often a spatial tool for organizing data and conceptualizing mental processes such as thought and memory. In Newton, order is also used as part of the underlying framework that allows us to conceptualize space and time (and parts of space and time) themselves. Casey notes the repetition of placial terms in this passage, describing them as 'Symptomatic of the irrepressible role of place in *specifying* any systematic thinking about space, above all absolute space'.[36] Again, the significance is at the epistemological rather than ontological level and these ideas of identity and specification are tools for being able to think about and discuss space and motion.

There is however a flaw in using absolute space as a conceptual backdrop for relative spaces, places, and motions. As Newton points out, motion and rest are distinguished in relative terms:

> motion and rest, in the popular sense of the terms, are distinguished from each other only by point of view, and bodies commonly

[35] Casey, p. 144.

[36] Casey, p. 146.

> regarded as being at rest are not always truly at rest. (*Principia*, p. 405)

Newton's discussion of place continues:

> But since these parts of space cannot be seen and cannot be distinguished from one another by our senses, we use sensible measures in their stead. For we define all places on the basis of the positions and distances of things from some body that we regard as immovable, and then we reckon all motions with respect to these places, insofar as we conceive of bodies as being changed in position with respect to them. Thus, instead of absolute places and motions we use relative ones, which is not inappropriate in ordinary human affairs, although in philosophy abstraction from the senses is required. For it is possible that there is no body truly at rest to which places and motions may be referred. (*Principia*, pp. 410–11)

The lack of referentiality absolute space affords, makes it impossible to measure *against* it in any real way. This means it is impossible to tell whether bodies are at rest or are in uniform rectilinear motion. This is implied in Corollary 5:

> When bodies are enclosed in a given space, their motions in relation to one another are the same whether the space is at rest or whether it is moving uniformly straight forward without circular motion. (*Principia*, p. 423)

There is no way of knowing whether that given space is at rest or in motion.

Similarly, in Corollary 4, Newton concludes that 'the common center of gravity of all bodies acting upon one another (excluding external actions and impediments) either is at rest or moves uniformly straight forward' (*Principia*, p. 421). The either/or construction (*vel*… *vel*) highlighting the fact that which state is the correct one is unknown.[37] Under Leibniz's theory of the identity of indiscernables, as there is no way of telling the two states apart, then they should be considered the same thing. However, this does not feel satisfactory against Newton's absolute framework. There is a real distinction, just not one we are able to perceive. Newton writes:

[37] *Principia* (1687), p. 17.

> Moreover, absolute and relative rest and motion are distinguished from each other by their properties, causes, and effect. It is a property of rest that bodies truly at rest are at rest in relation to one another. And therefore, since it is possible that some body in the regions of the fixed stars or far beyond is absolutely at rest, and yet it cannot be known from the position of bodies in relation to one another in our regions whether or not any of these maintains a given position with relation to that distant body, true rest cannot be defined on the basis of the position of bodies in relation to one another. (*Principia*, p. 411)

Newton admits the inability to determine true rest based on relative positions, and even suggests a fudge in considering the fixed stars as absolutely at rest, but ultimately admits true rest as an unknown.

The epistemological rather than ontological nature of these structures of space is felt in Newton's recourse to imagination and understanding in describing them. In *De Gravitatione*, he writes that:

> Space is extended infinitely in all directions. For we cannot imagine any limit anywhere without at the same time imagining that there is space beyond it. (*PW*, p. 23)

The human inability to imagine a limit is given as a reason for the infinity of space. In going on to describe a line 'greater than finite', Newton continues:

> Nor can anyone say that this is infinite only in imagination, and not in fact; for if a triangle is actually drawn, its sides are always, in face, directed towards some common point, where both would meet if produced, and therefore there is always such an actual point where the produced sides would meet, although it may be imagined to fall outside the limits of the physical universe. And so the line traced by all these points will be real, though it extends beyond all distance. (Ibid.)

This passage posits space, experienced in the imagination, as non-material (i.e. outside the limits of the physical universe), and possibly even non-geometric (beyond all distance), but still real, still fact. This is a very abstract notion of reality, partly mathematical, partly philosophical, and reliant on the imagination.

This abstract notion of reality is also redolent of Newton's view of the literal status of scripture. In a letter to Burnet of January 1681, Newton describes Moses's description of the creation:

> As to Moses I do not think his description of the creation either Philosophical or feigned, but that he described realities in a language artificially adapted to the sense of the vulgar. Thus where he speaks of two great lights I suppose he means their apparent, not real greatness.[38]

Neither is this accommodation a simple translation; he also writes, 'and yet the things signified by such figurative expressions are not Ideall or moral but true.'[39] The act of artificial adaptation and the figurativeness of the expressions somehow does not reduce the truth value of what is communicated. Andrew Janiak, in a paper that hypothesizes that Newton's conception of absolute space was initially developed in the early 1680s to deal with theological issues concerning the maintenance of Biblical creation alongside the physical laws of nature, interprets this letter as proof of Newton's rejection of the idea of accommodation (in a metaphorical sense) and relates it to his subsequent thinking on the distinction between absolute and relative space along the lines of what is 'real' and what is 'apparent'.[40] Janiak argues that for Newton, scripture always refers to apparent ideas and motions, which, like the relative, are ones adapted to the sense of the vulgar. So it is not real, and yet it is not metaphorical. It is a literal description of how things *appear*, not how they *are*. In this way Newton manages to accommodate, for example, both the Biblical truth that the sun travels around the earth, with the scientific truth that the earth revolves around the sun.

There is a sense in which absolute and relative truths are dependent on each other, like two sides of a coin. Newtonian dynamics requires a certain configuration of space and time — a four-dimensional differentiable manifold — in order to be

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[38] *Correspondence*, II (1960), 331.

[39] *Correspondence*, II, 333.

[40] Andrew Janiak, 'Newton's Conception of Absolute Space: A New Hypothesis', a talk given at University College London (24 October 2010).

understood, and that structure is dependent on a concept of absolute space. However absolute space is replete with epistemological issues as we can only experience relative space whereas, to human minds, absolute space can only ever be experienced conceptually. This posed a problem for those who believed Newton was positing absolute space as an ontological or metaphysical reality, but does not pose any such problem if we understand it as an epistemological construct, employed to enable us to do Newtonian physics. It also poses an epistemological problem as there is an implicit value judgement in the 'apparent' nature of the relative, tainted with preconceptions. Newton negotiates our inability to deal directly with abstractions by working with the contingent relative, but reframing it in the context of the absolute, combining the empirical with the conceptual in order to abstract from the senses and eliminate preconceptions. This way of thinking and working is also implicit in the tension between perception and abstraction felt in Newton's two-dimensional diagrams of four-dimensional accelerating paths and in the simultaneous literal and abstract reality of his thought experiments about mathematical objects that are real but do not exist within the physical universe, or possibly even within geometry.

God and Space

As I briefly touched on in the first section of this chapter, Newton connects theology and natural philosophy through causality and the design argument, and treats the study of nature as akin to worship and the study of God. As Janiak shows us, there is also a parallel — and possibly a developmental link — between Newton's thinking on the nature of the real and the apparent in relation to scripture, and his thinking on the relative and absolute natures of space. In the General Scholium, Newton relates the epistemological problems of natural philosophy to the epistemological problem of knowing God: 'there is no direct sense […] by which we know innermost substances; much less do we have an idea of the substance of God' (*Principia*, p. 942). He posits the partial solutions of learning of God through his creation: 'We know him only by his properties and attributes and by the wisest and best construction of things and their final causes', and analogy with the human: 'all discourse about God is derived through a certain similitude from things human, which while not perfect is nevertheless a similitude of some kind' (*Principia*, pp. 942–43). This is a similar tension to that between the real and apparent, the relative and absolute, the sensory and the abstract that has been under discussion throughout this thesis. The question of how we can know God through our relative experience, and of how God is related to the concept of absolute space in Newton's portrayal will be our concern for the rest of the chapter.

The General Scholium starts with a criticism of Descartes's theory of vortices, showing by calculation that the actual motions of the planets and comets are disproportional to those expected if vortices are assumed. Newton then discusses air resistance, similarly asserting that the celestial spaces above the atmosphere of the earth — like Boyle's vacuum — lack resistance and so the orbits of planets must be continuous (Newton's nod to Boyle emphasizing the role of artificial experiment in understanding natural laws through the theory of universal applicability to states beyond the scope of human verification). Newton next ponders causation, deducing from the mechanical system that there must be a non-mechanical cause for these regular motions; planets, while persevering in their orbits by the laws of gravity, could not have acquired those positions in the first place by means of those laws. The free movement and eccentric orbits of comets also suggest a non-mechanical cause. The elegance of the system and the serendipitous placement of bodies within it inspire Newton to assert 'the design and dominion of an intelligent and powerful being' (*Principia*, p. 940). The discussion turns to the nature of God and his relation to the universe: his supreme dominion and his relation to duration and space.

Newton relates God to space and duration as follows:

> He is eternal and infinite […], that is, he endures from eternity to eternity, and he is present from infinity to infinity […]. He is not eternity and infinity, but eternal and infinite; he is not duration and space, but he endures and is present. He endures always and is present everywhere, and by existing always and everywhere he constitutes duration and space. (*Principia*, p. 941)[41]

The distinction between being and constituting duration and space is both subtle and confusing and it is easy to sympathize with those such as Berkeley and Leibniz who

[41] NB the second edition reads 'he constitutes duration and space, eternity, and infinity'.

assumed Newton to be identifying God with space.[42] The idea that God is not duration and space but constitutes duration and space seems contradictory, but I think analogy with his patterned expression about eternity and infinity can help us unravel the meaning here. The Latin reads: '*Non est æternitas & infinitas, sed æternus & infinitus; non est duratio & spatium, sed durat & adest.*'[43] When Newton writes that he is not 'eternity and infinity' (*æternitas & infinitas*), but is 'eternal and infinite' (*æternus & infinitus*), the move from noun to adjectival forms repositions the concepts as attributes of God rather than as ontological states. The repeated sentence structure suggests that 'he endures and is present' (*sed durat & adest*) is to 'duration and space' (*duratio & spatium*), as 'eternal and infinite' is to 'eternity and infinity'. That is to say, that enduring and being present are attributes of God but that he is not identified with duration and space in any ontological way. Like absolute space, it is a more abstract conception. The subsequent sentence expands on the concepts of enduring and being present in the context of God's eternal and infinite nature, and as such is really a subset of 'but he endures and is present', and so the phrase 'he constitutes duration and space' (*durationem & spatium constituit*) is placed in a position of contrast to the idea of God *being* duration and space (*non est duratio & spatium*). As such, I reject an interpretation of 'constitutes' as 'be[ing] the elements or material of which the thing spoken of consists', favouring as applicable here the definitions: 'To set, place', 'To set up, ordain, establish, appoint, determine', and 'To frame, form, make (by combination of elements)'.[44]

De Gravitatione, which also positions itself against Cartesian relationalism and ideas of place, supports this reading of the relationship between God and space in Newton's thought. Newton writes:

> But I see what Descartes feared, namely that if he should consider space infinite, it would perhaps become God because of the perfection of infinity. But by no means, for infinity is not perfection except when it is attributed to perfect things. (*PW*, p. 25)

[42] On Berkeley and Leibniz on Newton and space see Geoffrey Gorham, 'Newton on God's Relation to Space and Time: The Cartesian Framework', *Archiv für Geschichte der Philosophie*, 93 (2011), 281–320 (p. 281).

[43] Isaac Newton, *Philosophiae Naturalis Principia Mathematica* (London: William and John Innys, 1726), p. 528.

[44] *OED*, 8; 1a; 3; 5.

Newton explicitly addresses the question of the identity between God and infinity, asserting that space and God are not identical, and neither are they identical by means of their shared attribute of infinity.

However, having made a distinction between being and constituting duration and space, Newton in the next paragraph of the General Scholium writes:

> He is omnipresent not only *virtually* but also *substantially*; for action requires substance. In him all things are contained and move, but he does not act on them nor they on him. (*Principia*, p. 941)[45]

As with the ideas of space discussed above which are simultaneously real and abstract, there is a seeming contradiction in God's omnipresence being described as both virtual and substantial. However, the nature of this substantiality is confused: Newton writes that God does not act on bodies nor they on him, which undermines the need for the condition of substantiality in the idea that 'action requires substance'. The idea of God as a container in which bodies move also suggests that perhaps this is a special understanding of substantiality. Newton had earlier stated that celestial spaces must be empty (like Boyle's vacuum) because of the lack of drag and the disproportionate movements of the planets and comets; it makes no sense to rid these spaces of Cartesian vortices only to fill them again with another physical substance. In the next sentence, Newton confirms that 'the bodies feel no resistance from God's omnipresence', but he does not explain his description of God as being omnipresent substantially (*Principia*, pp. 941–42). It is possible that the idea of God as a container, but one which has no interaction with the bodies moving within it, is related to the idea of absolute space as an epistemological backdrop to the movement of bodies, and that the substantiality referred to here is the necessary and essential reality of the presence of God, but does not include the same sort of material substantiality as bodies.

Newton also asserts that extension is not an accident inhering in subjects, that is, that space exists independently of body:

> Moreover, since we can clearly conceive extension existing without any subject, as when we may imagine spaces outside the world or

[45] NB Newton's note attached to *move* cites classical and Biblical authors as authority for this belief.

> places empty of any body whatsoever, and we believe [extension] to exist wherever we imagine there are no bodies, and we cannot believe that it would perish with the body if God should annihilate a body, it follows that [extension] does not exist as an accident inhering in some subject. (*PW*, p. 22)[46]

Newton also provides against the argument that relating God to space occasions the assertion that he is like a body:

> Moreover, lest anyone should for this reason imagine God to be like a body, extended and made of divisible parts, it should be known that spaces themselves are not actually divisible, and furthermore, that any being has a manner proper to itself of being present in spaces. (*PW*, p. 26)

Again, space and body are distinguished from one another by means of their properties. That space is not divisible adds credence to it being epistemological rather than metaphysical.

There is similar uncertainty over the status of the identification between God and space in Newton's famous description of space as an 'emanative effect' of God in *De Gravitatione*:

> Space is an affection of a being just as a being. No being exists or can exist which is not related to space in some way. God is everywhere, created minds are somewhere, and body is in the space that it occupies; and whatever is neither everywhere nor anywhere does not exist. And hence it follows that space is an emanative effect of the first existing being, for if any being whatsoever is posited, space is posited. And the same may be asserted of duration: for certainly both are affections or attributes of a being according to which the quantity of any thing's existence is individuated to the degree that the size of its presence and persistence is specified. (*PW*, p. 25)

Newton's list of beings that relate to space in some way includes three different kinds of being — God, created minds, and bodies. The distinction of the three, and particularly the inclusion of minds, suggests that for Newton there is no requirement for a being's

[46] Square brackets follow Janiak's text.

material substantiality to necessitate space. A similar reading can apply to the idea of space as an 'emanative effect' (*effectus emanativus*) of God.[47] The concept of emanation can apply to both material and immaterial things, and even things with a more ambiguous status, for example Henry More, who did equate absolute space with spiritual (yet immaterial) extension, uses 'emanative' to describe the procession of the Holy Ghost.[48] It can be interpreted in a similar way to the idea of God constituting space and duration discussed above, that is to say, that space emanates from God as a necessary and consequential framework of his existence: God exists and therefore the space in which he exists must also exist. This also answers for the connection between the eternity and immutability of God and space: 'space is eternal in duration and immutable in nature because it is the emanative effect of an eternal and immutable being' (*PW*, p. 26).

I think it is also possible to read this framework as mental and epistemological. When Newton describes space as an 'emanative effect' of God on the grounds that 'if any being whatsoever is posited [*posito*], space is posited [*ponitur*]', he creates a necessary link between space and existence, but in doing so also creates a parallel between the act of God occasioning space and the act of the creaturely imagining of space. *Pono*, *ponere* can be literally translated as 'to place', but also includes more figurative meaning which describe mental acts of placing. It is in this period that the English word 'posit' develops an extended meaning in logic and philosophy of 'to put forward' or 'to postulate' – a mental placing in addition to the original meaning of a physical act of placing.[49] This resonates with Newton's argument that space exists because we cannot think that it does not:

> although we can possibly imagine that there is nothing in space, yet we cannot think that space does not exit […]. This is manifest from the spaces beyond the world, which we must suppose to exist (since we imagine the world to be finite), although they are neither revealed to us by God, nor known through perception […]. But it is usually believed that these spaces are nothing; yet indeed they are spaces.

[47] For Latin text see Isaac Newton, 'De Gravitatione et æquipondio fluidorum', Cambridge University Library, MS Add. 4003, <http://www.newtonproject.sussex.ac.uk/view/texts/normalized/THEM00093> [accessed 5 April 2014] (p. 18).

[48] Henry More, *Paralipomena Prophetica* (London: 1685), p. 471, quoted in *OED*, 'emanative', 1.

[49] *OED*, 2a. The first usage in this context listed by *OED* is from 1697.

> Although space may be empty of body, nevertheless it is not itself a void; and something is there, because spaces are there, although nothing more than that. (*PW*, pp. 26–27)

The same tools are used in imagining space as are used in conceiving of phenomena beyond our perception, and there is a reality to space, even if it is empty of body and yet not itself a void.

Another controversial aspect of Newton's portrayal of the relationship between space and God is the idea of space as God's 'sensory' in the 'Queries' to the *Opticks*:

> Is not the sensory of animals that place to which the sensitive substance is present, and into which the sensible species of things are carried through the nerves and brain, that there they may be perceived by their immediate presence to that substance? And these things being rightly dispatched, does it not appear from phenomena that there is a being incorporeal, living, intelligent, omnipresent, who in infinite space, as it were in his sensory, sees the things themselves intimately, and thoroughly perceives them, and comprehends them wholly by their immediate presence to himself[.] (*PW*, p. 130)

This passage suggests that the immediate co-presence of God and all things allows his intimate knowledge of them. It is a spatial conception of God's omniscience, relating it to his omnipresence, and using the analogy of the sensorium from the animal world to describe the location — infinite space — for this meeting of perceiver and perceived. In the Leibniz-Clarke correspondence, Leibniz (perhaps disingenuously, or perhaps as a result of the infamous missing *tanquam*) takes Newton literally, claiming that 'Sir Isaac Newton says that space is an organ which God uses to perceive things', a view still upheld by some modern critics.[50] Even without the *tanquam*, I think it is possible to read Newton's query less literally, and indeed do so *because* of the spatiality of the idea. If the sensorium is infinite space itself, it is of the same magnitude as God and is co-present with him. As such, the notion of the sensorium must either be a metaphor, or an aspect of God as a whole being and not an organ, which is but a part of a being. That

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[50] Leibniz/Clarke 1717, First Letter (2000), p. 4, quoted in Gorham, p. 281. The phrase 'as it were' did not appear in some copies of the *Opticks*; see Alexander Koyré and I. Bernard Cohen, 'The Case of the Missing *Tanquam*,' *Isis*, 52 (1961), 555–66. See also Barbour, p. 629.

there is no need for a separate organ is implicit in the notion of the sensory of God, which comes from the idea that he is intimately present with all things, and that therefore his whole (spatial) being is like a sensory.

Newton explicitly states that the world is not to be considered the body of God, despite the analogy of the sensorium:

> we are not to consider the world as the body of God, or the several parts thereof, as the parts of God. He is a uniform being, void of any members or parts, and they are his creatures subordinate to him, and subservient to his will; and he is no more the soul of them, than the soul of man is the soul of the species of things carried through the organs of sense into the place of its sensation, where it perceived them by means of its immediate presence, without the intervention of any third thing. The organs of sense are not for enabling the soul to perceive the species of things in its sensorium, but only for conveying them thither; and God has no need of such organs, he being everywhere present to the things themselves. (*PW*, pp. 138–39)

Newton compares the metaphor of the sensorium of God to the place of sensation in man to establish the relation between God and creation as one of subject and object of perception, not any more metaphysical or ontological link. He also makes an analogy between the sensorium of God and the will of man with regard to their control over the physical universe and the human body respectively (*PW*, p. 138) thus reinforcing the sense of relation between human experience and the conception of God.

There is a similar idea of the expansiveness but indivisibility of mind in *De Gravitatione*:

> And just as we understand any moment of duration to be diffused throughout all spaces, according to its kind, without any concept of its parts, so it is no more contradictory that mind also, according to its kind, can be diffused through space without any concept of its parts. (*PW*, p. 26)

Newton compares mind to the structure of a plane of simultaneity (duration diffused throughout all spaces), asserting its ability to be present throughout space without being divided. This passage comes shortly after the quotation given above about God and space not being divisible (ibid.) and thus there is a sense that Newton is thinking about the mind of God (although there is nothing to say that this does not also apply to the minds of men). Another possible result emphasized by the idea of the sensorium of this identification or co-existence between God and absolute space (if the space under discussion is infinite and indivisible then it is absolute), is that God himself is a witness to absolute space and to the relation of relative space and motion to it.

It is intriguing that discussions of the relation between God and space are intertwined with musings on the perception and thought of God and man. Immediately between the passages from the General Scholium quoted above on eternity, infinity, space, and duration, and on God being omnipresent both virtually and substantially, Newton describes:

> Every sentient soul, at different times and in different organs of senses and motions, is the same indivisible person. There are parts that are successive in duration and coexistent in space, but neither of these exist in the person of man or in his thinking principle, and much less in the thinking substance of God. Every man, insofar as he is a thing that has senses, is one and the same man throughout his lifetime in each and every organ of his senses. God is one and the same God always and everywhere. (*Principia*, p. 941)

Newton seems to be positing a unity to man's collective experiences of sense or thought that transcends the linear and divisible experience of time and space. He then draws an analogy between this and the idea that God's omniscience is unified, even though it occurs across all times and spaces. This perhaps echoes the layer of abstract mathematical thought in which man is able to conceive (if not perceive) of absolute space.

In describing the unity of God, Newton writes:

> It follows that all of him is like himself: he is all eye, all ear, all brain, all arm, all force of sensing, of understanding, and of acting, but in a way not at all human, in a way not at all corporeal, in a way utterly unknown to us. (*Principia*, p. 942)

Newton separates the image of God into parts (all eye, all ear), making it comprehensible and comparable to man, at the same time as asserting that each of these parts is the whole. He also asserts that the way these things are is not at all human and utterly unknown to us. On the one hand this gives the comparison with the united and collective sensory experience of man the force of elevating man to something beyond his mundane capacity, but on the other highlights the impossibility of it, echoing his distinction between what is true or absolute versus what is apparent or relative and framed in such a way to be understood by the vulgar man.

The analogy between human and divine experience here appears to have been formed in reverse, partly because the passage starting 'Every sentient soul' is an addition of the third edition, and also because the unification of the separate senses does not seem like a natural description of human experience but rather a back formation from his thinking of God's omniscience in spatial terms and of using accommodated, anthropomorphic imagery to describe God's sensing and understanding. The gap between human and divine experience is also emphasized in the passage from the 'Queries' to the *Opticks* on infinite space as the sensorium of God. The passage continues:

> [God] who in infinite space, as it were in his sensory, sees the things themselves intimately, and thoroughly perceives them, and comprehends them wholly by their immediate presence to himself: of which things the images only carried through the organs of sense into our little sensoriums, are then seen and beheld by that which in us perceives and thinks. And though every true step made in this philosophy brings us not immediately to the knowledge of the first cause, yet it brings us nearer to it, and on that account is to be highly valued. (*PW*, p. 130)

After the analogy between the sensory of creatures and the ('as it were') sensory of God, there is a contrast between the immediate presence and thus intimate perception of God in his infinite and co-present sensory, and the more limited perception of man whose experience of objects is mediated through our organs and located separately in our finite and *little* sensoriums. However, as with the stepped approach of Hooke and even the aspirational nescience of Boyle, the second sentence of this quotation validates the human experience as worthy, for it is by these means that we can come closer to knowledge of the first cause. While the 'true steps' of Newton's text only explicitly refer to human observations of the natural world, and thus the potential for knowledge of God through his creation, it is suggestive that this idea of narrowing the gulf and approaching knowledge of the first cause comes after a comparison between human and divine experiences and perceptions. A quick or imprecise reading could easily misinterpret this as support for the idea that human and divine perception are comparable and perhaps even on the same continuum. As Richard Cotes observes, ‘his [Newton’s] tremendous genius, enodat[es] each of the most difficult problems and reach[es] out beyond the accepted limits of the human’ (*Principia*, p. 398). Although Newton resists the literal possibility of comparison between human and divine perception, the juxtaposition of these ideas suggests an aspirational trajectory.

In Newton’s presentation there is a mixture of both potential comparison and literal disunity in man and God’s experience of space, a sense of shared yet different experience. Newton draws an analogy with ‘a blind man with no idea of colors’ to express our ignorance of ‘the ways in which the most wide God senses and understands all things’ (*Principia*, p. 942). In describing God as ‘most wide’, Newton emphasizes the idea that his spatial extent is related to his perceptions, a detail echoed in the ambiguity of how to read ‘all things’ — while our experience would be of a sequence of parts, the wideness of God is such that he can comprehend an entire plane of simultaneity at once, or even the whole manifold. But it also emphasizes the spatiality of our understanding of God, and this is another way in which Newton’s God is like his conception of space; there is a need for a fixed absolute backdrop, something consistent and all pervasive even if not wholly comprehensible, against which the relative, experiential world can be understood. For Newton this consistency and all pervasiveness is figured spatially (temporally too, but with greater emphasis on the spatial), as if this aspect, like the notion of absolute space as an epistemological construct, is necessary to be able to think of God.

Conclusion

Newton places a lot of confidence in man’s ability to discern the frame of nature and to figure out the mechanical workings of the universe. He posits an approach that prizes the certainty of its facts and refuses to feign hypotheses, preferring instead to mark off areas of knowledge — such as primary causes — as admittedly unknown. In order to make these standards of certainty workable and practicable with the capacities of man and the current state of knowledge, he admits contingent knowledge and asserts that, methodologically, it is to be treated as if it is certain, until proven otherwise. In order to accommodate the limited perceptual faculties of man, Newton also assumes a consistency to the laws of nature, inferring from what can be observed or deduced by experiment, principles that are to be applied to bodies universally (albeit contingently). This sense of unity and universality has a distinctly spatial feel to it, emphasizing the sense of location in man's relation to creation and the things of the world. This is also felt in Newton's portrayal of absolute and relative space. In order to make sense of dynamics, a concept of absolute space must be projected as a backdrop and corrective recontextualization to the relative space and motion that we can perceive. I have argued that this absolute space is an epistemological construct rather than an ontological reality, even if there is an abstract or mathematical sense in which is it more 'true' than its relative counterpart. This abstract or mathematical mental space, underpinned by absolute space, is key for understanding Newton's work, for example in understanding the two-dimensional diagrammatic representations of four-dimensional paths. Absolute and relative space are intimately connected as we cannot deal directly with abstracts and must always deal with them in terms of each other. This relation is echoed in Newton's exploration in spatial terms of the nature of God, who must be similarly understood in terms of an abstract corrective to a relative understanding.

Chapter 4

John Milton and Literary Space

Introduction

Angelica Duran, in her significant book *The Age of Milton and the Scientific Revolution*, argues that Milton's literature is 'as much a part of the project that Francis Bacon called the advancement of learning as were the optical lenses, air pumps and intravenous syringes created by early modern scientists'. Although it is not itself 'science', Milton's work does more than merely reflect or praise the work of scientists, and with its concern about the development of knowledge, it participates in a cultural project wider than the specific disciplinary divisions arising at the time.[1] As I hope I have demonstrated in the previous three chapters, applying techniques of literary analysis to the works of Hooke, Boyle, and Newton confirms the idea that 'science' does not just happen in laboratories, under lenses, or in experiments and then gets reported in publications. Natural philosophy is much wider ranging in its remit and also takes place — for both practitioners and readers — on the page and in the mind, both in terms of exploring the philosophical questions about knowledge that underpin it, and also at the level of praxis in the performing of thought experiments and in the processing and understanding of data in order to construct knowledge. In this chapter, I follow Duran in reading Milton as participating in a wider cultural project of 'science' that does so much more than just summarize or comment on the findings, theories, or practice of contemporary natural philosophers, and that actually engages with the same fundamental questions about knowledge, and even uses some cognate methods — on the page and in the mind — to test and explore the human experience of the world around us. Again, space is central. As well as providing a thematic point of contact between Milton's theological epic and the work of contemporary natural philosophers, the use and representation of spatiality are intimately connected with questions of epistemology.

Paradise Lost is a poem directly concerned with space and spatiality. It includes the creation of and travel between worlds, battles for territory, encroachments and banishments, and characters engaged in astronomical contemplation. However, while Milton's presentation of space has enough detail to demonstrate his interest and literacy in contemporary astronomy and cosmology, he does not seem to be concerned with outlining a particular cosmology or system of physics. Like Raphael's refusal to answer Adam's astronomical probing in Book VIII, Milton does not reveal enough to allow the

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[1] Duran, p. 3.

reader to determine any particular system. Alastair Fowler notes that Milton's cosmos relates coherently to the cosmos as understood by Milton's contemporaries, but can be variously interpreted as Copernican, Ptolemaic, or Tychonic.[2] What I believe stands out more in Milton's work, is his exploration of the creaturely experience — or indeed experiences, for they are subjective, various, and multiple — of space, and its relation to the quest for knowledge.

In this chapter I trace the theme by exploring how Milton engages, not with systems or theories, but with the more fundamental questions of natural philosophy that we have seen at the core of work by Hooke, Boyle, and Newton. In the first section, I outline the anxieties and convictions of Milton's epistemology and the methods he encourages and demonstrates for coming to knowledge. In the second section, I consider his exploration of the ideas of the legibility of nature and the relationship between the visible and invisible worlds; and in the final section, I examine the presentation of space in *Paradise Lost*, considering the similarities between the observed, experimental, and conceptual spaces of Hooke, Boyle, and Newton, and the spaces created by Milton's literary imagination — spaces which are themselves created to test and explore, and which have an intimate relationship with thought and the development of knowledge.

Epistemology

The epistemological beliefs and the methodologies for attaining and developing knowledge written into Milton's oeuvre betray similar themes and tensions to those of the natural philosophers considered in this thesis. Milton shows faith in the human capacity for knowledge and a belief in founding knowledge on human experience and sensory data, but there is some tension between these beliefs and an awareness of the limits of human knowledge because of its basis in corporeality. There is also an anxiety about what man *should* know. These anxieties are especially prominent with regard to the desire for higher knowledge, such as the secrets of nature, and ultimately, God. However, like the natural philosophers, Milton does not abandon his quest for truth, and

[2] *Paradise Lost*, ed. by Fowler, p. 34. References to the poem are to this edition and are given by book and line number, parenthetically in the text.

in many cases employs similar strategies for allowing knowledge to progress in spite of its limits. These strategies include the ennobling of subjective and sensory human experience, the framing of human knowledge in the context of a process of learning, the acceptance of the contingency of human knowledge, the embracing of human reason, and the assumption of the consistency of nature.

In *Paradise Lost* there are numerous anxieties about the status and capacity of human knowledge. Milton makes Raphael the mouthpiece for some of these anxieties as the archangel frets over educating Adam:

> how shall I relate
> To human sense the invisible exploits
> Of warring spirits[?] (V. 564–66)

Raphael questions his ability to communicate angelic events specifically to Adam's 'human sense'. Throughout the poem we are reminded of the incomprehensibility of God who, 'invisible | Amidst the glorious brightness' (III. 375–76), is portrayed only in accommodated forms, and also of the limited mental and perceptual faculties of even unfallen man who must rely on Raphael for revelation of things, 'Unknown, which human knowledge could not reach' (VII. 75). Raphael worries about the legitimacy of sharing information with Adam, of unfolding 'The secrets of another world, perhaps | Not lawful to reveal' (V. 569–70), suggesting that there might be limits to what man should know, and perhaps offering support against the curiosity of practices such as natural philosophy. He tells Adam that his commission is 'to answer thy desire | Of knowledge *within bounds*' (VII. 119–20, my emphasis). There are also frequent reminders of the disparity between the understanding of fallen and unfallen man. As Stanley Fish illustrates with his notion of the 'guilty reader', the reader's experience is dialectical and he or she is repeatedly asked to make a distinction between him or herself and Adam and Eve, always reading through the lens of his or her corruption, even where the described Edenic scene is pure, such as in the sensuous description of Eve in Book IV.[3] In Book IX we witness the changes in Adam and Eve as they fall: their 'inmost powers | Made err' (IX. 1049–50), and 'their minds | How darkened' (IX.

[3] Stanley Fish, *Surprised by Sin*, 2nd edn (London: Macmillan, 1997), p. 142.

1053–54). Ultimately they are hidden from the face of God and angel, whose sight now dazzles them (XI. 1080–84; X. 723–24).

However, despite these anxieties, which would seem to align Milton with traditional narratives of the impassable gulf between man and God, and the irreparable breach between the pre- and post-lapsarian states, Milton offers a generally positive view for the knowledge capabilities of man, both before and after the fall. There are numerous occasions where Milton celebrates and elevates the bodiliness of sensory experience. As Christopher Tilmouth shows, the passions guide Adam and Eve to God and their intuitive worship of him through wonder, love, and sensuous revelry.[4] Neither does Raphael disdain corporal food, admitting that angels also possess 'every lower faculty | Of sense' (V. 410–11) and falling to his meal with Adam and Eve, 'with keen despatch | Of real hunger' (V. 436–37). Even Satan is arrested by the sensual description of Adam and Eve, not for any reason of depravity, but because 'so lively shines | In them divine resemblance' (IV. 363–64). Satan sees reference to God in their outward appearance, and this sensory experience provokes an emotional reaction of grief and wonder in the fallen angel and shows him at his best and closest to redemption. Lee A. Jacobus describes an epistemology that 'credits sensory experience in Heaven, Hell and on Earth', showing that while for Milton, sensory perception is not sufficient in itself, it is not a detestable or unreliable guide for knowledge and is necessary if knowledge is to be had at all.[5]

In *Paradise Regained*, Milton similarly emphasizes the substantial humanity of the Son. He is the 'True image of the Father', but is also described as 'enshrined | In fleshly tabernacle, and human form'.[6] The word *fleshly* focuses on the gross corporeality of the incarnation, but the words *enshrined* and *tabernacle* elevate that fleshy casing with their worshipful, religious connotations, *enshrined* in particular suggesting the 'appropriateness' of the container for what it houses.[7] The description of God's purpose in the incarnation emphasizes the importance of Jesus's bodily humanity

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[4] Christopher Tilmouth, *Passion's Triumph over Reason* (Oxford: Oxford University Press, 2007), pp. 190–92.

[5] Lee A. Jacobus, *Sudden Apprehension: Aspects of Knowledge in 'Paradise Lost'* (The Hague: Mouton, 1976), pp. 8–10.

[6] 'Paradise Regained', in *Complete Shorter Poems*, ed. by Carey, IV. 596, 598–99. Further references, denoted *PR*, are to this edition and given by book and line number parenthetically in the text.

[7] *OED*, 'enshrine' 1a.

to his task: 'His weakness shall o'ercome Satanic strength | And all the world, and mass of sinful flesh' (*PR*, I. 161–62). There is a potentially dual reading here and as well as the primary meaning that Satan and the world and mass of sinful flesh will be overcome by the Son's weakness (i.e. his assumption of human form), one can also read 'the world' and/or 'the mass of sinful flesh' as being in apposition to 'his weakness' and so actually a part of what will overcome Satanic strength.[8]

In *Paradise Lost*, Milton portrays knowledge as growing out of human experience and physical observation. There are gestures towards the tradition that held Adam to have innate knowledge — such as Adam's instinctive looking to heaven (VIII. 257) and awareness of a maker (VIII. 278) — however his knowledge of his self and the other objects of creation seem to derive from observation, interpreted with reason. For Adam, Eden is a place of learning and his behaviour features exploration and experiment. In his description of his nativity he recounts: 'Myself I then perused, and limb by limb | Surveyed, and sometimes went, and sometimes ran' (VIII. 267–68), this example encompassing examination, trial, and bodily experience. The biblical episode from Genisis 2. 19 where Adam names the animals — traditionally used as evidence of Adam's innate knowledge — is alluded to in the poem:

> I named them, as they passed, and understood
> Their nature, with such knowledge God endued
> My sudden apprehension. (VIII. 352–54)

The idea of *sudden apprehension* seems to support the idea of innate knowledge, but there is a hint of tension between this suddenness and the act of the animals passing before Adam, which gives a sense of the historicity of experience, a relationship between spatial and temporal experience, emphasized by the homonym *passed*/past.[9] In *Tetrachordon*, Milton writes that Adam, 'had the wisdom giv'n him to know all creatures, and to name them according to their properties' (*CPW*, II, 602). Here, the gift is not knowledge itself, but the wisdom to know, a subtle difference that places more emphasis on Adam's own agency in his coming to knowledge. Combined with the

[8] This reading is supported by Milton's citation of Romans 8. 3, '"God having sent his own Son formed like flesh, liable to sin"', in the discussion of the dual nature of Christ in *De Doctrina* (*CPW*, VI, 419).

[9] On this and other resonances of the passed/past homonym see William Poole, *Milton and the Idea of the Fall* (Cambridge: Cambridge University Press, 2005), pp. 165–66.

Aristotelian idea of naming ‘according to their properties’, this gift is portrayed as a set of categorical principles to be applied upon phenomenological encounter rather than an innate knowledge of the thing itself. While Genesis 2. 19 is not related in full in *Paradise Lost*, the naming we are shown — where Adam demonstrates fit pairings of animals based on verbal patterning — has the feel of an experiment to test the categorical boundaries of these names, rather than a sudden God-given apprehension of their natures.

> they rejoice
> Each with their kind, lion with lioness;
> So fitly them in pairs thou hast combined;
> Much less can bird with beast, or fish with fowl
> So well converse, nor with the ox the ape;
> Worse then can man with beast, and least of all. (VIII. 392–97)

Adam starts with *lion* and *lioness*, their fitness expressed in the near congruence of variant forms of *lion*. Then come the less apt, but alliterative, *bird* and *beast*, *fish* and *fowl*. The regression continues with *ox* and *ape*, which have no patterning, and finally *man* and *beast* who not only have no shared features to unite them, but are pulled in opposite directions along the line by internal rhymes with other words, *can* and *least*, thus emphasizing the verbal incongruity that exemplifies the categorical unfitness of their natures to be paired. This is perhaps a lexical and poetic rendering of a natural historical exploration of categories.

By presenting these methods of learning in Eden, Milton suggests that even the most ideal state of human knowledge is not something fixed, but a process, and indeed a process that includes learning from empirical evidence derived from the senses. Working to the same conclusion, Karen Edwards argues against readings that interpret fallen Eve’s praise of experience as her ‘Best guide’ (IX. 808) as Milton’s condemnation of experience. Edwards shrewdly points out that the actual objection to Satan’s method isn’t its reliance on experience, but its fraudulence; Satan falsifies the experimental data he claims, not having eaten the fruit himself. If Eve had held to her own reading of nature’s ordered ways she would have been able to see the talking snake for the monstrosity it was.[10] One of the things that makes Satan's lie so seductive is his claim, with the influence of the fruit, to have 'Considered all things visible in heaven, | Or earth, or middle' (IX. 604–05). It is seductive precisely because this is the method that, according to Milton, man must use in order to come to knowledge.

These interpretations of the validity of empirical knowledge, square with Milton's own syllabus of learning as set out in *Of Education*, which departs from classical education not only in the subjects covered — to which Milton added geography, physics, applied mathematics, and natural philosophy amongst others — but also in the methods deemed suitable:

> To set forward all these proceedings in nature & mathematicks, what hinders, but that they may procure, as oft as shall be needfull, the helpfull experiences of Hunters, fowlers, Fishermen, Shepherds, Gardeners, *Apothecaries;* and in the other sciences, *Architects*[,] Engineers, Mariners, *Anatomists*[.] (*CPW*, II, 393–94)

As well as reading texts, the students are encouraged to consult the *experiences* of practitioners. As Duran describes, Milton's syllabus emphasizes humans, not theories.[11]

As well as ennobling the necessarily corporeal aspect of human data collection, Milton also provides metaphysical and moral solutions to Raphael's anxieties, through the angel's own reason and revelation. The hierarchy of beings may cause anxiety about the limited capacity for knowledge of lesser beings, but it also allows for the possibility of man's ascension up the hierarchy and for methods of his understanding by means of various accommodations. As well as his rhetorical query in Book V about the capacity of 'human sense' to understand the exploits of angels (quoted above), Raphael also wonders:

> to recount almighty works
> What words or tongue of seraph can suffice,
> Or heart of man suffice to comprehend? (VII. 112–14)

[10] Karen L. Edwards, *Milton and the Natural World: Science and Poetry in 'Paradise Lost'* (Cambridge: Cambridge University Press, 1999), pp. 15–18.

[11] Duran, p. 156.

These two quotations taken together emphasize a three-tiered hierarchy, which shifts with perspective, rather than just a divide between man and higher beings. Like Boyle's comparisons between the natural philosopher and the child, or the anatomist and the illiterate man, used as analogies for the disparity between human and diving knowledge, there is a subjective relativity to the status of knowledge. The quotation from Book V establishes the difference between man and angel, but this from Book VII is more ambiguous about that distinction. The gulf here is between God and angel, *and* between God and man; in this case, angel and man are on a much more equal footing, as the connective *or* and repeated *suffice* help to suggest, although we still assume the second-level distinction between angel and man because of what we remember from Raphael's speech in Book V about the disparity between the recounting of angels and the comprehension of man. This reading emphasizes Raphael's role as an intermediary between man and God, between different states of comprehension, and furthermore emphasizes the lack of fixity of a creature's place in the hierarchy of beings. As with Boyle, Hooke, and Newton, there is a sense of limit, but not necessarily a strict definition of where, or how permanent that limit is.

This potentially fluid hierarchy also echoes Raphael's message about the potential for creatures to ascend a material hierarchy. He suggests this when discussing the angelic digestion of earthly food ('corporeal to incorporeal turn' (V. 413)), the connections between the parts of the universal ecosystem ('the grosser feeds the purer' (V. 416)), and finally in his revelation of a traversable, neoplatonic conception of divine matter:

> one first matter all,
> Indued with various forms, various degrees
> Of substance, and in things that live, of life;
> But more refined, more spirituous, and pure,
> As nearer to him placed or nearer tending
> Each in their several active spheres assigned,
> Till body up to spirit work, in bounds
> Proportioned to each kind. (V. 473–79)

The connection between refinement of comprehension and refinement of matter further validates the foundation of knowledge on sensory information, and echoes the ideas seen in Boyle, Hooke, and Newton of human knowledge as contingent and incremental.

Milton, like Hooke and Newton, uses Bacon's image of knowledge as stepped, concluding from Raphael's lessons that, 'In contemplation of created things | By steps we may ascend to God.' (V. 511–12).

The particular method that Raphael lights on for communicating across levels is simile:

> what surmounts the reach
> Of human sense, I shall delineate so,
> By likening spiritual to corporal forms,
> As may express them best[.] (V. 571–74)

This is evocative of the use of analogy with what is known (by metaphor and simile) in order to understand the unknown, for example in Hooke's descriptions of microscopical findings or Boyle's speculations about the invisible air. Milton expresses a similar idea in *Areopagitica* when he writes of the search for truth: 'To be still searching what we know not, by what we know' (*CPW*, II, 551).

Adam takes away a methodology of the contemplation of nature from Raphael, and yet numerous critics have read Raphael's injunction to Adam, 'heaven is for thee too high | Too know what passes there; be lowly wise' (VIII. 172–73) in relation to the archangel's anxiety over what is lawful to reveal (quoted above), and concluded that it is intended as a rebuke to Adam's curiosity about the workings of the heavenly bodies and an instruction against the investigations of astronomy and natural philosophy. However, despite the loadedness of the theme of curiosity in its foreshadowing of the dangers of the tree of knowledge, the position is not so clear cut. Not only does the injunction to 'be lowly wise' contradict Adam's earlier lesson that the contemplation of creation can allow man to ascend to God, the narrator also seems to have disregarded the presumed lesson of humility himself: while Adam obediently checks the roving of his mind from things remote from use, Milton does not. Adam says, 'Therefore from this high pitch let us descend | A lower flight' (VIII. 198–99), but we remember that Milton's poem, 'with no middle flight intends to soar' (I. 14). I believe caution is needed with the simplistic reading of Raphael's instruction to 'be lowly wise' as an injunction against curiosity. Raphael, having heard Adam's query about the efficiency of heavenly motions, does not criticize our first father:

> To ask or search I blame thee not, for heaven
> Is as the book of God before thee set,
> Wherein to read his wondrous works[.] (VIII. 66–68)

Raphael also re-emphasizes the value of contemplating and reading creation. Barbara K. Lewalski's reading of this scene is helpful here. She notes that Adam's query grows out of Raphael's creation story and the tension between its geocentric portrayal and the hint at the possibility of other inhabited worlds, rather than suddenly stumbling upon forbidden or presumptuous knowledge. Lewalski writes that instead, 'as usual', Adam:

> proceeds by trial and error in his intellectual growth: he starts with certain faulty assumptions and formulations, and it is Raphael's province to teach him the proper spirit in which to approach natural science.[12]

Furthermore, Lewalski notes that Adam does not conclude that the earth moves, he just asks questions about its purpose, and that Raphael's tone is not censorious, the archangel even inviting Adam to consider more advanced theories and suggesting that the geocentric model might be a result of limited human perspective (VIII. 114–18).[13] The major point of Lewalski's reading is that Raphael is not there to resolve questions of natural science for man and as such he leaves the confirmation or otherwise of scientific facts to Adam to work out himself.

Milton sends Raphael on a voyage through space, which, as Malabika Sarkar suggests, allows for the combination of cosmic speculation and experience in the poem.[14] In the context of Adam, I think it also allows for the *contrast* of these two modes as Raphael chooses not to reveal to Adam the cosmological truths of the poem, but the reader has witnessed Raphael's journey, thus foregrounding the different relative perspectives of the two characters. Raphael's concern is with the attitude Adam brings to enquiry; he does not limit Adam's enquiry, but rather urges contentment with what is revealed and redirects Adam's attention to his primary concerns and joys, which are

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[12] Barbara Kieffer Lewalski, 'Innocence and Experience in Milton's Eden', in *New Essays on 'Paradise Lost'*, ed. by Thomas Kranidas (Berkeley: University of California Press, 1969), pp. 86–117 (p. 108).
[13] Lewalski, pp. 108–09.
[14] Malabika Sarkar, '"The Visible Diurnal Sphere": Astronomical Images of Space and Time in *Paradise Lost*', *Milton Quarterly*, 18 (1984), 1–5 (p. 2).

humanistic.[15] The emphasis in Lewalski's reading is on learning and methods of thought, not on prohibition of subject matter. As such it is possible to see Raphael as encouraging human learning through natural philosophical means as well as revelation. It is also possible to see Raphael's urging for Adam's contentment, not as a stricture, but as a recommendation of an epistemological method that accepts the contingency and relativity of human knowledge — as we have seen in Hooke, Boyle, and Newton. Similarly, the redirection onto the humanistic is compatible with empirical methods of learning, and with the idea of the natural philosopher of the seventeenth century as an underbuilder participating in a wider, collaborative project to be developed by later generations.

One of the key aspects of Milton's epistemology is the rejection of the dichotomy between the pre- and post-lapsarian human conditions, which both allows us hope for the capacity of fallen man and allows us to see the lessons of unfallen man (including his ways of learning and creating knowledge) as directly applicable to the fallen reader. The catastrophizing tendencies common to orthodox seventeenth-century commentaries offer a woefully limited view of human moral and epistemological capability after the fall: pre-lapsarian Adam was credited with superior knowledge and clearly reasoned thought, expressed in a perfect word-thing language; whilst his fallen counterpart languished with partial knowledge and confused thought, mediated by the senses and clouded by the passions. This understanding of the fall encouraged, even mandated, the rejection of emotions and sensory experiences as its signs and tainted artefacts. However, as Poole shows, Milton's heterodox narrative does not hold the two states to be fixed or discrete: 'the mind is degraded, but not utterly so'.[16] By avoiding strict dichotomy, Milton presents a holistic notion of human capability, an extension of *felix culpa*, which encompasses the very 'flaws' that make man fallen.

When Milton writes in *Of Education* that 'The end then of learning is to repair the ruins of our first parents by regaining to know God aright' (*CPW*, II, 366–67), he simultaneously acknowledges the fall and its attendant loss of knowledge, but also suggests that the epistemological consequences of the fall are repairable, and knowledge of God possible. Indeed the way to achieve this is through our most fallen faculties. Milton continues:

[15] Lewalski, pp. 110–12.

[16] Poole, *Milton and the Idea of the Fall*, p. 145.

> and out of that knowledge to love him, to imitate him, to be like him, as we may the neerest by possessing our soul of true vertue, which being united to the heavenly grace of faith makes up the highest perfection. But because our understanding cannot in this body found it selfe but on sensible things, nor arrive so cleerly to the knowledge of God and things invisible, as by orderly conning over the visible and inferior creature, the same method is necessarily to be follow'd in all discreet teaching. (*CPW*, II, 367–69)

The knowledge of God, which is the end of learning, is to be founded on *sensible* and *visible* things, i.e. the contemplation of created things. Here, Milton relies on an assumption of the consistency of nature between the visible and invisible realms to both make possible the pursuit of higher knowledge, and to give an epistemic value to the study of visible things in the process of coming to know God. Although this is presented as the method of repairing the damage of the fall, in *Paradise Lost*, we see this method of learning used *before* the fall. Raphael, despite his anxieties about the disjunction in referentiality between man and angel, exemplifies Milton's educational principles and makes visible the invisible with resort to simile in his teaching of Adam.

Further to this, in *Of Education*, the knowledge of God does not make up the highest perfection in and of itself, but must lead to love and the imitation of God (as near as possible) through the possession of virtue. I have shown that the idea that knowledge of the creation is a pious act of devotion leading to love of God, rather than an impious and impudent curiosity leading away from God, is exemplified in the writings of Boyle, Hooke, and Newton. The idea is similarly expressed by Milton's Adam, whose plea to Raphael for knowledge of the creation is couched:

> if unforbid thou mayst unfold
> What we, not to explore the secrets ask
> Of his eternal empire, but the more
> To magnify his works, the more we know. (VII. 94–97)

The act of loving and imitating God suggested in *Of Education* again ennobles the bodily and the human by means of virtue. In *Areopagitica* (composed the same year as *Of Education*), Milton identifies virtue with the passions: 'Wherefore did he creat passions within us, pleasures round about us, but that these rightly temper'd are the very ingredients of vertu?' (*CPW*, II, 527). In *Areopagitica*, the emphasis is also on fallen man proving his virtue by the very markers of his fallenness; the 'dust and heat' (*CPW*, II, 516) in which the race is to be run evoke the bodily punishment of Adam at Genesis 3. 19.

Finally, in the passage from *Of Education*, the soul must be united to the 'heavenly grace of faith', a type of knowledge predicated on the absence of rational or empirical proof.[17] The relationship of faith to grace in this construction creates a dependence between the two; faith takes on an air of God-given belief, and divine grace is implied to be dependent on the faith of the believer. While Milton strongly believes in empirical methods as the basis for human knowledge, he also leaves room for the divine gifts that are necessary to ultimate knowledge. In *Paradise Lost*, knowledge learned from interacting with the world sits alongside and combines with revelations from God and his messengers. The acknowledgement of the lack in human knowledge that needs to be made up by grace, actually makes human knowledge more secure. Like the nescience that we see in natural philosophy — particularly in the work of Boyle — this lack both protects the validity of human knowledge by not claiming too much for it to bear, and also leads Milton (and Adam) to further knowledge of the human condition. Adam's seemingly innate knowledge of his maker is inferred from not knowing his own beginning (VIII. 251), or who he is (VIII. 270), and his feeling that he is happier than he knows (VIII. 282). Further, Adam draws praise of his knowledge from God precisely for admitting its limits:

> To attain
> The height and depth of thy eternal ways
> All human thoughts come short[.] (VIII. 412–14)

To which God replies:

> Thus far to try thee, Adam, I was pleased,
> And find thee knowing not of beasts alone,
> Which thou hast rightly named, but of thyself,
> Expressing well the spirit within thee free,

[17] On the tension between reason and faith in puritan thought see John Morgan, *Godly Learning: Puritan Attitudes towards Reason, Learning, and Education, 1560–1640* (Cambridge: Cambridge University Press, 1986), p. 41.

My image[.] (VIII. 437–41)

Adam, using his very lack of knowledge to substantiate the point, demonstrates that he has knowledge of himself in relation to God, and it is the ability to work this out that expresses the image of God in man.

That nescience is a part of unfallen Adam's experience points to the key epistemological tool that brings together various different aspects of knowledge acquisition: reason. Adam's unfallen knowledge is not perfect in its completeness, but in his capacity to reason and determine relationships, to learn, based on observations of the world around him, what he knows and what he doesn't know. Reason would not be necessary if knowledge was complete, and similarly free will would be meaningless. In the quotation above, Milton's God emphasizes that it is the freedom of the spirit within man that is his image. As Milton says of Adam in *Areopagitica*: 'when God gave him reason, he gave him freedom to choose, for reason is but choosing; he had bin else a meer artificiall *Adam*, such an *Adam* as he is in the motions' (*CPW*, II, 527). Similarly, in *Paradise Lost*, Milton's God states that 'reason also is choice' (III. 108), questioning the value of obedience paid to necessity rather than to him.

Milton is confident of man's capacity to choose correctly and to make appropriate value judgements. In *Areopagitica*, he cites Dionysius Alexandrinus's vision of God who tells him, 'Read any books whatever come to thy hands, for thou art sufficient both to judge aright, and to examine each matter' (*CPW*, II, 511). Further, in *Paradise Lost*, Milton's God deems man, 'Sufficient to have stood, though free to fall' (III. 99). As Thomas Fulton describes, *Areopagitica* shows why a prescribed set of beliefs cannot produce knowledge. He writes, 'Milton shows that the natural conditions of reason require freedom in order for people to know what they profess,' and also emphasizes that the search for truth is necessarily fragmented, since 'epistemological fragmentation causes constant trial and assists in the process of discovery'.[18]

Our nescience provides the opportunity for reason, that is, for choice, which combines the knowledge gleaned from observation of the natural world with man's faculty for reason, his most divine attribute. Again, this combines 'scientific', philosophical, or rational knowledge with faithful knowledge because of the guidance of the inner spirit. The proliferation of biblical referencing persuades the reader of the

[18] Thomas Fulton, '"Areopagitica" and the Roots of Liberal Epistemology', *English Literary Renaissance*, 34 (2004), 42–82 (pp. 59, 67).

authority of the poem, however, it is anachronistic in its narrative context and so there is ambiguity as to what these references mean for the characters. Is Milton's scriptural reference only there for the reader, or is divine revelation another source of knowledge available to the poem's characters, occurring in tandem with their experiential learning? In *De Doctrina*, Milton asserts his belief in the authority of scripture but states that scripture is twofold: there is the external written scripture, and also an internal scripture 'engraved upon the hearts of believers' by the holy spirit (*CPW*, VI, 587). The anachronistic inclusion of biblical language, especially in the mouths of characters, suggests this second form. The scripture of the heart offers an integrated sense of revealed knowledge, linking revelation, reason, and the body (and thus sensory knowledge). The heart is emphasized as corporeal by Milton's citation of II Corinthians 3. 3 on the '"fleshly tablets of the heart"' (*CPW*, VI, 586), but could also be understood as the seat of the mind, soul, or emotions (*OED*, 5a, 6a, 9a).

By quoting scripture not yet written, Milton also creates a continuity between pre- and post-lapsarian language. Milton reminds us of Isaiah 59. 21, asserting that the spirit in us, and the word of God in our mouths, is not obliterated by the fall (*CPW*, VI, 587). Ironically this shifts authority away from scripture and more to the inward spirit of God found in man, i.e. his capacity to reason and judge, and so to a confidence in his ability to know. Fulton cites a passage from *De Doctrina*:

> God's providence committed the contents of the New Testament to such wayward and uncertain guardians […] so that this very fact might convince us that the Spirit which is given to us is a more certain guide than scripture, and that we ought to follow it. (*CPW*, VI, 589)

Fulton argues that to Milton's mind, 'God created an uncertain [Biblical] narrative *in order* to produce an internal authority, thus enhancing the process by which knowledge is obtained.'[19]

Our ultimate exemplar in how a human should act in relation to his knowledge and faith is of course the Son. In *Paradise Regained*, the Son's strength, and ironically his wisdom, comes from faith, both in the guidance of his inner spirit and his trust that his limited, human knowledge will suffice. When he goes into the wilderness, it is not a carefully calculated decision, but an impulse: 'by some strong motion I am led' (*PR*, I.

[19] Fulton, p. 61.

290). The term *motion* suggests the passions,[20] but the context also suggests this impulse or motion to be potentially God given; there is a sense that God is directing Jesus by means of his passions.[21] This impulse is not a full revelation and relies on faith, which can only be demonstrated in the absence of knowledge. The Son states:

> to what intent
> I learn not yet, perhaps I need not know;
> For what concerns my knowledge God reveals. (*PR*, I. 291–93)

The Son acknowledges his state of not knowing and renounces his need for knowledge, trusting to the aptness of God's revelation. Milton echoes this sentiment in 'When I Consider How my Light is Spent', with the line, 'They also serve who only stand and wait'.[22] These pious yet human examples encapsulate the idea from *Of Education* of active passivity in the faith of grace; the passivity of waiting for revelation and grace, underwritten by active choice and active faith.

In Book IV of *Paradise Regained*, Satan tries to tempt the Son with knowledge:

> Be famous then
> By wisdom; as thy empire must extend,
> So let extend thy mind o'er all the world,
> In knowledge, all things in it comprehend. (*PR*, IV. 221–24)

He offers Pagan philosophy concluding, 'These rules will render thee a king complete | Within thyself' (*PR*, IV. 283–84), the line break giving 'Within thyself' more the feel of a caveat than a promise and emphasizing the closedness of Satanic reason to revelation or external data.

Satan's use of the word *knowledge* undermines him as its primary definition is of 'acknowledgement or recognition' (*OED*, 1) and Satan's failure throughout *Paradise Regained* is his refusal to allow himself to acknowledge or recognize the identity of the Son. This is even more apparent in the word *wisdom*, which, as well as its primary

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[20] Richard DuRocher, 'Samson's "Rousing Motions": What They Are, How They Work, and Why They Matter', *Literature Compass,* 3 (2006), 453–69 (pp. 455–56).

[21] DuRocher, pp. 463–64 similarly argues for the passions as the point of interaction between God and Samson.

[22] *Complete Shorter Poems*, p. 333, l. 14.

meaning, is one of the manifestations of the divine nature in Christ and used as one of his titles, the 'Wisdom of the Father' or simply 'the wisdom' (*OED*, 1c).[23] The ironic truth hidden in Satan's words is that anything beyond the statement 'Be famous then by wisdom' is extraneous. Wisdom and knowledge are not exactly synonymous and Satan's move from one to the other reveals a lack of subtlety in his own knowledge and emphasizes his lack of appreciation for the additional qualities of wisdom that encompass the ability to judge rightly (*OED*, 1a) over and above simple recognition.

While it might be tempting to read Satan's offer in line with Milton's views against the restriction of non-orthodox material in *Areopagitica*, it is Jesus who truly exemplifies Milton's position, having the sufficiency to judge of its value as knowledge. The Son, who responds 'sagely' (*PR*, IV. 285) to Satan, shows more wisdom and knowledge than Satan, not because he reveals possession of knowledge, but because he recognizes its limits and lack of necessity.

> Think not but that I know these things, or think
> I know them not; not therefore am I short
> Of knowing what I ought: he who receives
> Light from above, from the fountain of light,
> No other doctrine needs, though granted true. (*PR*, IV. 286)

The Son dismisses the pagan learning offered, pausing only to praise the nescient Socrates, who resisted the feigning of hypotheses and the falseness of premature systematization: 'The first and wisest of them all professed | To know this only, that he nothing knew' (*PR*, IV. 293–94).

The Legibility of Nature, and Visible and Invisible Worlds

The discussion of Milton's epistemology thus far betrays several connections to the ideas of visuality and spatiality which have been the core focus of this thesis and which will make up the rest of this chapter. The reliance on sensory information has an obvious connection to visuality, but there is also a more complex dynamic — which we

[23] In *Paradise Lost*, God describes the Son as 'my wisdom' (III. 170).

have seen in our natural philosophers as well — in the relation of the visible to knowledge of what is beyond the visible.

As discussed above, the method of learning Milton outlines in *Of Education*, and indeed the method that will allow access to knowledge of invisible things, is the 'orderly conning over the visible and inferior creature'. That this boundary between the visible and invisible is in Milton's mind in *Paradise Lost* is clear from his invocation to Urania (the muse of astronomy) to help him 'see and tell | Of things invisible to mortal sight' (III. 54–55).

When Raphael discusses with Adam what the focus of his study should be, he says that heaven is 'as the book of God before thee set, | Wherein to read his wondrous works, and learn' (VIII. 67–68). This comparison between creation and the book of God is evocative of the idea of the book of nature, perhaps doubly so due to the anachronism of the comparison — for Adam, the book of God, i.e. scripture, has not yet been written and so the creation and his inner spirit are the only books of God he can read. The idea of reading nature is (as demonstrated in the previous chapters) related to semiotic questions of natural philosophical enquiry, in particular the dynamic between what is seen and what is therefore known, and the level of interpretation required by mankind to deduce or infer knowledge from what he or she sees.

Fish suggests that 'By using language to point up the distortion that results wherever fallen man attempts to make sense of the world around him, Milton passes judgement on the scientific and linguistic optimism of his own century'.[24] However, I think Fish mistakenly presumes a positivist version of science that does not fit either the epistemologies of the natural philosophers studied in this theses, or Milton's own approach in his characters' exploration of the world through language. In Milton's linguistic exploration of the relationship between what is seen and known, it is — perhaps surprisingly — the inherently imperfect, referential nature of fallen human language, the gap, rather than congruence, between sign and referent, that facilitates his (and indeed Adam's) exploration and testing both of semiotic structure itself, and of the relationships between created objects.

When Adam first sees Eve he says:

> I now see
> Bone of my bone, flesh of my flesh, myself

[24] Fish, p. 107.

> Before me; woman is her name, of man
> Extracted. (VIII. 495)

Adam renders Genesis 2. 23 almost exactly, but adds the phrase 'myself before me', highlighting the metaphorical aspects of the description against the more literal truth of Eve's nativity from Adam's rib. The addition emphasizes the importance of referentiality, identity, and self-knowledge in arriving at truth and shows Adam exploring these themes as he fathoms out his relation to Eve. However, we also see flaws in Adam's reasoning as he tries to turn Eve into a sign of himself in his confusion of unity and identity. 'Myself before me' flags the tension between understanding *bone* and *bone* as either one or two signs, and the potential danger in reading too literally and abandoning the elasticity of referential language.

Even Milton's God uses metaphorical language to suggest semiotic relationships, telling Eve that her image, seen reflected in the lake, is her self, 'What there thou seest, fair creature is thyself' (IV. 468), and describing Adam to her, 'he | whose image thou art' (IV. 471–72). By verbally equating her with her reflected image, and calling her the image of Adam, God teaches Eve to distinguish but also to see the relationships between herself and others.[25] In Eve's recounting of her nativity, Adam again makes the mistake of literality, calling Eve: 'His flesh, his bone' (IV. 483) (referring to himself in the third person). This contrasts with God telling Adam that Eve is his 'likeness' (VIII. 450), and also God's description of the image relationship to Eve (quoted above) at IV. 471, just a few lines before. Adam later solidifies his (mis)identification of Eve in his decision to fall: 'Our state cannot be severed, we are one, | One flesh; to lose thee were to lose myself' (IX. 958–59). Further evidence of Milton's condemnation of Adam's literalism is clear from *Tetrachordon* where Milton disputes the interpretation of Genesis 2. 23 as mandate for 'the indissoluble bond of marriage', preferring a reading where it represents the 'unity of mind and heart' between spouses, not mere flesh (*CPW*, II, 602).

Nature in Milton's presentation acts as a sign for the causes of its creation, but — as in Boyle and Hooke — not in an immanent, revelatory way that equates sign with referent. This is why Raphael needs to teach Adam about seeing and interpreting nature in different ways, that is, with admiration rather than vain curiosity. By so doing, Adam

[25] This is of course problematic in other ways, as feminist critics such as Annabel Patterson have rightly pointed out.

can read nature correctly as a sign for the maker, instead of merely seeing his works and failing to make that interpretive connection to what lies beyond. In contrast, Satan exhibits a lack of imagination in his facetiously literal, pseudo-scientific reasoning:

> Doctrine which we would know whence learned: who saw
> When this creation was? Rememberest thou
> Thy making, while the maker gave thee being?
> We know no time when we were not as now;
> Know none before us, self-begot, self-raised
> By our own quickening power[.] (V. 856–61)

Satan's exclusive focus on worldly evidence in his 'critical scrutiny' of the creation tale, leads to his claim for autochthony and deprives him of any real understanding of God.

The fruit of the tree of knowledge provides a good example of nature as a sign that is not inherently legible. When Eve contemplates the fruit, she fixes her gaze on it (IX. 735) and it is seductive to her eyes and other senses, but nothing about its appearance to the sight or other senses gives any indication that it is forbidden, good, evil, or even particularly special. It is merely 'fair to the eye, inviting to the taste' (IX. 777). What is highlighted elsewhere as special about it, however, is its function as a sign. When describing the prohibition against the fruit of the tree of knowledge, Adam calls it:

> The only sign of our obedience left
> Among so many signs of power and rule
> Conferred upon us[.] (IV. 428–30)

The fruit is a sign of obedience, not necessarily an inherently magical object.

Another recurring epistemological theme in Milton's exploration of the relationship between visual signs and their referents, is that of deception and visual trickery. While Milton highlights the deceptive potential of sensory data, the physical act of seeing is related to cognitive functions such as recognition and evaluation, and often bound up with self-knowledge. The way through the confusion of sensory data is not in its outright rejection, but in an integrated and subjective way of being that acknowledges and uses the sensory and corporeal, at the same time as scrutinizing it, i.e. the application of reason and judgement. In *Paradise Regained*, Satan appears to the

Son in various guises, but unlike the vulnerable Lady of *A Masque Presented at Ludlow Castle* who trusts Comus's rural disguise, or Eve who ignores her misgivings about the serpent, Jesus sees through the deception immediately. He says to Satan, 'I discern thee other than thou seem'st' (*PR*, I. 348), creating a sense of dual vision between what is discerned and what seems.[26] He questions why Satan would suggest he distrust God, 'Knowing who I am, as I know who thou art?' (*PR*, I. 356), linking self-knowledge to the ability to unravel deceptive identities. The narrator immediately describes Satan as 'th' Arch-fiend now | Undisguised' (*PR*, I. 357–58) suggesting the performative nature of the Son's statement of recognition. This contrasts strongly with Satan's inability or refusal to recognize Jesus as the Son of God.

In *Paradise Lost* there is a failure (by Eve and by Uriel) to see past Satan's disguises which contributes to the circumstances of the fall. Satan's snake-like disguise and actions are designed 'to lure her eye' (IX. 518), the visuality of this emphasized at line 528 with a further mention of Eve's eye. Eve is described as 'unwary' (IX. 614), and the 'credulous mother' (IX. 644). However, this failure of recognition does not seem to be morally loaded, for the narrator says after Uriel has been tricked by Satan, 'Neither man nor angel can discern | Hypocrisy' (III. 682–83). While this contributes to the circumstances of the fall, the moral aspect is firmly the breaking of the prohibition.

In *Paradise Regained*, another form of visual trickery is found when Satan presents Jesus with visions to tempt him from God. The vision of Rome (offered as worldly power) is impossible; it is 'presented to his eyes | Above the height of mountains interposed' (*PR*, IV. 38–39) and allows him to see, simultaneously, inside and outside of houses. Its strangeness is highlighted:

> By what strange parallax or optic skill
> Of vision multiplied through air, or glass
> Of telescope, were curious to inquire. (*PR*, IV. 40–42)

We cannot know from the text how Satan showed Jesus this vision (by optical instruments augmenting natural sight, or by supernatural means), but in employing the language of scientific instruments, Milton taps into anxieties about the veracity of such images mediated by optical instruments, and highlights the interpretive role of the subjective observer. As Maura Brady argues in her analysis of the telescope in *Paradise*

[26] *Discern* can refer to distinction both with the mind and with the eyes (*OED*, 2, 5a).

Lost, 'the instrument is no apparatus of godlike vision across distance, but one that embodies the difficult work of seeing and knowing, the material, pedagogical, and rhetorical craftsmanship without which knowledge is impossible.'[27]

Satan's line, 'so well I have disposed | My airy microscope' (*PR*, IV. 56–57), suggests his hand in the mode of viewing, and his use of *microscope* for *telescope* results in a confusion of scale (the microscope making small things appear larger rather than distant things nearer), and thus possibly suggests an attempted obfuscation of value. This Satanic vision, a layer of falsehood provided by some intermediary deception, is similar to the obscuring film over Adam's eyes in Book XI of *Paradise Lost* (bred by the first fruit which Satan falsely claimed to give clearer sight), which Michael has to remove to enable Adam to see truly.[28] The vision Satan provides the Son reminds us that visual data has its own rhetoric.

Rather than dispelling these visions, the Son instead engages with the difficult work of seeing and knowing. Despite warnings of its deceptiveness, the visual stimulus is not dismissed as false; rather, the Son's faith and reason are strong enough that these illusions are not persuasive to his judgement. In response to the vision of Rome, Jesus is described as 'unmoved' (*PR*, IV. 109); despite the effect on his senses, he does not respond passionately, a contrast to his Godly impulse to journey into the wilderness in the first place. The Son replies to Satan:

> Nor doth this grandeur and majestic show
> [...] allure mine eye,
> Much less my mind. (*PR*, IV. 110–13)

This reveals a relationship between thinking and seeing based on evaluation. It recalls the Lady of *A Masque* who, whilst drugged, uses her experience of confused vision to ward her mind against temptation, using a metaphor of visual disguise to unwrap Comus's false reason:

> this juggler

[27] Maura Brady, 'Galileo in Action: The 'Telescope' in *Paradise Lost*', *Milton Studies*, 44 (2005), 129–52 (p. 50).

[28] Milton links these visions by comparing Adam's hilltop to the one from which Satan shows Jesus earth's kingdoms (*PL*, XI. 381–84).

> Would think to charm my judgement, as mine eyes
> Obtruding false rules pranked in reason's garb.[29]

The Son and the Lady are able to use their faithful judgement to draw on an inner vision, distinct but related to their corrupt, sensory experiences. Like Adam using his lack of knowledge as a basis for forming knowledge, or Milton and Raphael approaching the invisible by means of the visible, the Son and the Lady use their experience of distorted vision to reason out a true one. As Brady describes of the telescopic occlusions in *Paradise Lost*, 'they are offered as a challenge to the reader to accept a limited perspective and confusion as necessary conditions of the search for knowledge, and to make of them something useful.'[30]

We find this relationship between distorted and true vision within the realm of subjective, fallen experience in Milton's emotional exploration of his own blindness and visionary sight. In 'Methought I Saw my Late Espoused Saint', the poet closes: 'But O as to embrace me she inclined | I waked, she fled, and day brought back my night', the simple binary of day and night working in tension with the complex truth of the poet's subjective experience of *my* night, where sign and referent have become personalized, relative, and thus altered from their normal designation.[31] He remembers the original mapping of day and night, light and dark from his sighted years, but his daily experience is of darkness, and it is night that offers the vision of dreams. Similarly, the vatic poetry of *Paradise Lost* goes beyond the typical paradox of revealed vision in blindness (a common trope that Milton nods to with his reference to Tiresias at III. 35) and entwines spiritual and corporal sight. In the opening to Book III Milton moves through an anguished description of his blindness to an invocation of the celestial light to plant inner eyes, purged from mist (ideas pre-echoing the circumstances of Adam's vision), that he 'may see and tell | Of things invisible to mortal sight' (III. 54–55). And yet, despite the opportunities his blindness affords for spiritual sight, the sensory sight lost is not presented as base for its corporality, nor incomplete for its fallenness, but is genuinely mourned and worried about — not least for its role in achieving wisdom — in words pre-echoing Eve's paean to nature, 'sweet is the breath of morn' (IV. 641).

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[29] *Complete Shorter Poems*, 'A Masque Presented at Ludlow Castle', ll. 756–58.

[30] Brady, 'Galileo in Action', p. 50.

[31] *Complete Shorter Poems*, p. 348, ll. 13–14.

> Thus with the year
> Seasons return, but not to me returns
> Day, or the sweet approach of even or morn,
> Or sight of vernal bloom, or summer's rose,
> Or flocks, or herds, or human face divine;
> But cloud instead, and ever-during dark
> Surrounds me, from the cheerful ways of men
> Cut off, and for the book of knowledge fair
> Presented with a universal blank
> Of nature's works to me expunged and razed,
> And wisdom at one entrance quite shut out. (III. 40–50)

Milton's blindness cuts him off from the views of God's creation our first parents had in Eden, from the creatures that allowed Adam to demonstrate his fit knowledge, and from the visible image of God in the face of man, still present even to fallen man.[32] The phrase 'book of knowledge' at line 46 connects his blindness with, and separates him from, man's contemplative purpose, discussed by Adam and Raphael. Milton creates a beautiful image in his visually evocative listing of dawn, sunset, vernal bloom, summer's rose, flocks, herds, and human faces, and yet it is an image that necessarily does not exist, a ghost image that creates itself in our minds at the same time as insisting on its absence. The repeated *returns*, used positively of the seasons and then negatively of Milton's visual experience, emphasizes this tension, with the idea of cyclical repetition evoking renewal and fecundity working against the infertile aporia of trying to recover something now lost to all but memory. The haunting quality heightens emotion, emphasizing the sense of loss and so allowing the reader to discern the value of this lost corporeal vision, even while acknowledging the worth of the poet's vatic gifts. However, this technique, holding sight and the absence of sight in tandem, is also suggestive of something greater than either in isolation.

This is at odds with the more typical Christian paradox of 'true vision', the mysterious, spiritual, revealed vision, in comparison to which physical sight becomes the blindness of corporeal attention, and physical blindness an opportunity for revelation.[33] The account of Adam's vision in Book XI has elements of this idea, but

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[32] See also XI. 353–54.

[33] Forrest G. Robinson, *The Shape of Things Known: Sidney's Apology in its Philosophical Tradition* (Cambridge MA: Harvard University Press, 1972), p. 31.

tempered by Milton's ennobling of fallen man. Michael removes the obscuring film from Adam's eyes, purges Adam's 'visual nerve' (XI. 415) with euphrasy and rue, and instils drops from the well of life. The effect is powerful:

> So deep the power of these ingredients pierced,
> Even to the inmost seat of mental sight,
> That Adam now enforced to closed his eyes,
> Sank down and all his spirits became entranced. (XI. 417–20)

The removal of the film, distinction of mental sight, and Adam's closed eyes suggest the rejection of corrupt, corporeal sight, and yet spirituality and mental sight are not divorced from the sensual organs. As Fowler notes, the treatment with euphrasy, rue, and water of life is symbolic of purging sin with gladness, repentance and grace.[34] On one level this supports the idea of needing to reverse the fallen corruption of the body and yet the application is directly to the eyes, their bodiliness emphasized by the anatomical term 'visual nerve'.[35] What is the value of rue (repentance) to the eyes if the senses do not have rational, intellectual capabilities? This suggests a monist position where bodily functions operate in an integrated way with intellectual and spiritual ones. Once Adam has been treated, rather than giving him a vision in his blind and swooning state, Michael raises him up and bids him open his eyes; Adam sees the future of mankind with spiritual and sensory vision operating concurrently.

We also find a dual sense of vision when we look at the accommodated presentation of God himself. Arnold Huijgen's analysis of divine accommodation illustrates the tension between a Platonic, transcendent idea of accommodation where the truth of God exists somewhere behind the so-called truth of revelation, and an immanent view in which there is held to be some truth or knowledge of God as he actually is in his accommodated revelation to man.[36] Neil Graves's analysis of *De Doctrina* reveals Milton's heterodox, immanent view, arguing for a synechdochic (rather than metaphoric) theory of scriptural accommodation, which aligns with the

[34] *Paradise Lost*, ed. by Fowler, p. 621, note to lines 413–15.

[35] While it is possible Milton used *nerve* in the sense of 'strength' as he does elsewhere, he would likely have known the anatomical usage of *visual nerve*, e.g. from Francis Bacon's *Sylva Sylvarum* (1626) (*OED*, '*visual*', 3a).

[36] Arnold Huijgen, *Divine Accommodation in John Calvin's Theology: Analysis and Assessment* (Göttingen: Vandenhoeck & Ruprecht, 2011), pp. 13–28, 36–42.

second idea of accommodation as outlined by Huijgen.[37] This is also close to Newton's idea of scriptural truth being real, but relative. Graves bases his argument on two idiosyncratic principles in Milton: that the accommodated image (the literal, textual image in scripture) should be the locus of understanding, and that this image is a veridical presentation of the subject, even though it does not contain the whole truth of the subject.[38] In his proof for the second principle, Graves cites from Chapter 2, 'God has revealed only so much of himself as our minds can conceive and the weakness of our nature can bear,' and lists the scriptural quotations with which Milton supports this: from Exodus (the back parts of God); Isaiah (a vision of God enthroned); John (no man has seen or heard God); and I Corinthians (seeing God in a mirror) (*CPW*, VI, 133). Graves's reading — that God has revealed himself and not merely a symbol for himself, albeit incompletely — is supported by his categorizing the quotations to form three parts of a pseudosyllogistical form of reasoning: 'Major Premise — No man can see God (Command); Minor Premise — Man has seen God (Experience); Conclusion — Man both does and does not see God, i.e., Man sees God either partially or merely parts of God.'[39] This fits with the idea of man's sufficiency to evaluate found in *Areopagitica*, and man's capability to come to some knowledge of God in *Of Education.* It also emphasizes the value of holistic subjective experience and the dual vision I have demonstrated in Milton's poetry.

While Graves's article discusses *De Doctrina*, his principles help achieve a more subtle reading of the accommodation of God in *Paradise Lost.* When Raphael comes to his solution of simile — 'likening spiritual to corporal forms, | As may express them best' (V. 573–74) — he continues with a suggestive unanswered question:

> Though what if earth
> Be but the shadow of heav'n, and things therein
> Each to other like, more than on earth is thought? (V. 574–76)

Raphael questions the extent of the relationship between heavenly reality and his accommodated narrative, suggesting that there might be a closer relationship than his

[37] Neil D. Graves, 'Milton and the Theory of Accommodation', *Studies in Philology*, 98 (2001), 251–72 (p. 252).

[38] Graves, pp. 257–60.

[39] Graves, p. 261.

initial framework of simile offers, and which Graves's synechdoche would satisfy. The phrase 'more than on earth is thought' is also provocative; who are these thinkers? Does Raphael refer to Adam and Eve, or does Milton's voice come in here too, referring to the fallen reader and the wider philosophical tradition?

The portrayal of God in *Paradise Lost* antagonizes the tensions between seen and unseen with its apophatic techniques, but this ultimately allows a dual experience of seeing and not seeing God. Milton's description of God at book III, lines 373–82, after the contemplation of man's impending fall and the elevation of the Son, invokes the negative way with adjectives 'immutable, immortal, infinite', describing God by what he is not. Throughout the passage the description of the 'invisible' God is concerned with spectacle. There is light and brightness and there are seemingly tangible objects: throne, cloud, shrine, God's skirts. However, these do not resolve themselves into an image, but contradict their visibility: the brightness dazzles, the throne is inaccessible, the cloud obscures, the shrine is but a simile. The only image we can truly visualize is that of the seraphim veiling their eyes from the view of God. It is by *this* understanding of visuality that we are able to 'see', but only in as far as we can see a negative image, in relation to which we hold an accommodated idea of the vision of God. This might seem a fairly traditional presentation, but remember that unfallen Adam used a similar method to reason about God, even in the presence of God. The high levels of spectacle emphasize the visual in this non-vision, recalling the phenomenon of Milton's description of his lost sight at III. 40, which held sight and the absence of sight in tandem. This earlier passage prepares the reader for the vision of God by teaching the technique of reading and imagining. That we might interpret Milton's passage in the same way as scriptural accommodation is authorized by its scriptural sources (the same as those cited in the discussion of accommodation in *De Doctrina*, referred to above) and the fact that this scene comes directly after Milton's invocation to the holy light and is framed as proof that Milton's request for prophecy has been granted. The reader is given the impression that Milton is indeed seeing and telling of things invisible to mortal sight.

The Literary Presentation of Space

In this section, I look at the way space and spatiality are described as a subject, how they are employed in the consideration of the theme of epistemology, and how they are used as a way of exploring human subjectivity and the relationships between humankind and his environment.

The first of Milton's settings encountered in *Paradise Lost* is hell. One might almost refer to it as an anti-description though for all its ambiguity. In the argument to Book I, hell is set up, not as a place in its own right, but in opposition to heaven, the emphasis being that the angels were 'driven out of heaven' and into 'the great deep'. It is located, 'not in the centre', but 'in a place of utter darkness, fitliest called chaos'. This requires some complicated mental gymnastics to accommodate as this negative location is dependant on the reader supposing heaven and earth as 'yet not made'. This is achieved by a typically Miltonic technique of simultaneously suggesting and undermining a concrete relation, telling us that hell is not locatable by its usual relation to heaven and earth, and furthermore placing it in context of a space — chaos — which is known more as an intangible 'what' rather than any sort of concrete 'where'. The only geographical feature described of hell is 'the burning lake', but at the close of the argument we are also told that, 'Pandaemonium the palace of Satan rises, suddenly built out of the deep', suggesting a confusingly unstable and mutable landscape.

When we reach the initial descriptions of hell in the poem proper, we are met with similar ambiguities. Hell, like much of Milton's epic scenery, is characterized by a vastness that is indeterminate. The location to which the fallen angels are hurled is first described as 'bottomless perdition' (I. 47), the word *bottomless* creating both a sense of epic proportion and a lack of concrete imagery or specific dimension, and *perdition* also carrying an abstract quality being both a state of being and the place of hell. Similarly, when Satan casts his eye and 'At once as far as angels' ken he views' (I. 59), Milton creates a sense of vast scope without giving any information. He does this entirely in terms of the extent and limit of Satan's own perception, rather than by any features of the landscape. Beyond the repeated insistence of the presence of fire, there is virtually no detail with which to conjure up the scene that is instead created with a more emotional rather than visual palette. We feel rather than see 'The dismal situation waste and wild, | A dungeon horrible' (I. 60–61), the 'sights of woe, | Regions of sorrow, doleful shades' (I. 64–65). Even the persistent imagery of fire is undercut by the revelation that its flames cast, ‘No light, but rather darkness visible’ (I. 63). The few details which crop up — ‘floods and whirlwinds of tempestuous fire’ (I. 77) — are not anchored enough to create a specific scene rather than a mood. Throughout the scene we get occasional references to parts of the setting, the ‘dreary plain’ (I. 180), the ‘upper, nether, and surrounding fires’ (I. 346), ‘hell’s concave’ (I. 542), but overwhelmingly the description is conveyed by comparative reference to either heaven or (anachronistically) earth, or by means of the fallen angel’s emotional or perceptual experience of it. We do start to get some sense of the scale of the setting when the fallen angels gain in confidence and correspondingly take firmer shape; the number of banners raised is ‘ten thousand’ (I. 545), a more specific measure than we have had thus far, but Milton still includes an array of shields ‘of depth immeasurable’ (I. 549) in the same sentence. Later the number of spirits is ‘millions’ (I. 609), again conveying vastness and hinting at the idea of measure with a numerate word, but both unspecific and so large as to be uncountable.

The one feature of hell that does receive specific description is the hill on which Pandæmonium is to be raised:

> There stood a hill not far whose grisly top
> Belched fire and rolling smoke; the rest entire
> Shone with a glossy scurf, undoubted sign
> That in his womb was hid metallic ore,
> The work of sulphur. (I. 670–74)

The description is used as a way of redirecting the narrative. The reader is given an approximate location, and several details of appearance, composition, and behaviour. We are also given information about how to read this landscape for what it reveals of its interior, how it works as a sign for something else. This is confirmed when the fallen angels, under the leadership of Mammon, ‘Opened into the hill a spacious wound | And digged out ribs of gold’ (I. 689–90). The landscape becomes a symbolic parody of Godly creation, an idea built upon by the praise for the work and for the architect of Pandæmonium at lines 731–32. The artificial structure that is Pandæmonium is, like the hill, given specific detail:

> The ascending pile
> Stood fixed her stately height, and straight the doors

> Opening their brazen folds discover wide
> Within, her ample spaces, o'er the smooth
> And level pavement: from the archèd roof
> Pendent by subtle magic many a row
> Of starry lamps and blazing cressets fed
> With naphtha and asphaltus yielded light
> As from a sky. (I. 722–30)

The detail here uses analogy with natural imagery ('starry lamps', 'as from a sky'), but in so doing emphasizes its artifice. This is also felt in the description of the 'smooth and level pavement' or the 'archèd roof'. As with the experiments of the natural philosophers there is a level of descriptive detail that is achievable in an instrumental or artificial setting. There is again a sense of vast space, 'stately height', 'discover wide within, her ample spaces' but also in this case one of bound: the structure stands 'fixed', and the adverb 'straight' also lends itself to this feel, connoting limit. Once inside Pandaemonium (I. 775–97), the sense of an artificial environment under scrutiny, as well as the sense of an unstable environment dependent on the perspective of the viewer, is further troubled by the strange distortions of scale that the fallen angels enact and which Milton's narrative applies.

Hell, this first location or setting of Milton's poem, creates a sense of geographical uncertainty and mutability, and is conveyed to the reader in a subjective rather than factual way. This is contrasted with the certainty that is available in a more artificial, constructed setting. As we shall see, this foreshadows the intimate connection between space and relative experience in Milton's epic, as well as connecting it to the ideas we have seen in the natural philosophers of this study of needing to demarcate experimental spaces (either physically or mentally) in order to construct knowledge.

In the introduction to this chapter, I reviewed Fowler's reading of *Paradise Lost* that acknowledges the indeterminacy of Milton's cosmos. As well as the possibility of Copernican, Tychonic, or Ptolemaic interpretation, there are also wider incongruities. While Satan and Raphael travel through an apparently continuous and homogeneous space on their voyages to Eden,[40] there are also references to older cosmological traditions, such as the 'crystàlline sphere' (III. 482) and the angels as stars (V. 708–09).

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[40] Satan, 'Down right into the world's first region throws | His flight precipitant, and winds with ease | Through the pure marble air his oblique way | Amongst innumerable stars' (III. 562–65). Raphael, 'through the vast ethereal sky | Sails between worlds and worlds' (V. 267–68).

Sarkar describes the astronomical images of space in *Paradise Lost* as 'keep[ing] alive the possibility of infinity in an otherwise finite universe' and the images of time as 'project[ing] the simultaneous presence of the temporal in the midst of eternity'. Her reading of the poem is of a world that is both 'at once measurable and immeasurable'.[41] Following Sarkar's cue about the simultaneity of finity and infinity in the poem, I propose that, rather than seeing Milton's systemic indeterminacy as a weakness, it is more usefully considered as akin to Newton's view of the true and apparent versions of creation, being both real in some way, but witnessed from different viewpoints.

The holding open of multiple cosmic possibilities in Milton's poem cultivates an awareness of the limits of the relative experience of space, as explored by means of the (differently) limited perspectives of the characters and narrator. In one of his cosmic vistas, Milton describes the angel Uriel moving in relation to the sun and the earth:

> Uriel to his charge
> Returned on that bright beam, whose point now raised
> Bore him slope downward to the sun now fallen
> Beneath the Azores; whether the prime orb,
> Incredible how swift, had thither rolled
> Diurnal, or this less volúble earth
> By shorter flight to the east, had left him there[.] (IV. 589–95)

The repeated *now*, 'now raised [...] now fallen', emphasizes the temporary nature of location in this description. The speculative second part of the quotation then effectively pans out on the scene, allowing the narrator to contemplate the movement of the two bodies, and to demonstrate that the directionality described in the first part is relative: the raised end of the sun beam, Uriel's downward slope, and the fallen sun. This is evocative of Newton in *De Gravitatione*:

> Gravity is the force in a body impelling it to descend. Here, however, by descent is not only meant a motion towards the center of the earth, but also towards any point or region, or even from any point. (*PW*, p. 36)

[41] Sarkar, p. 5.

Like Newton's flexible *descent*, the downward trajectory Uriel follows to the sun is not absolute, but relative to a specific viewpoint and to that specific configuration of moving bodies in that particular moment of time.

Milton's narrator presents two possible explanations for the fall of the sun beneath the Azores: the movement of the sun, or the movement of the earth. Perhaps the incredulity of the swiftness of the prime orb suggests doubt for the first of these hypotheses, but the sluggishness of the less voluble earth does not allow this to be uncontested (as we from our heliocentric perspective might be tempted to read it). Despite the trajectories of *downward* and *fallen*, both explanations remain possibilities, even from the vantage point of a narrator who can view these cosmic exchanges from space. It is also possible that for Uriel, moving towards it, the sun does not appear to be fallen. We share these vantage points and can create multiple images in our minds, demonstrating that even with the imagined, remote perspective of the narrator, we can only understand the motions of the heavens as relative. If we try to imagine these orbits without including a fixed backdrop of absolute space or any other points of reference we see how difficult it is to visually distinguish between the two hypotheses. Milton later returns to the question of which body moves when Adam asks Raphael about the 'numbered stars, that seem to roll | Spaces incomprehensible […] Round this opacious earth' (VIII. 19–23) and 'the sedentary earth, | That better might with far less compass move' (VIII. 32–33). By asking the question, Adam foregrounds the relative perspective of man watching the skies from the earth (which may or may not itself be moving). Raphael suggests possibilities — include heliocentrism — but demurs to answer, leaving the case uncertain and thus emphasizing the limitedness of the relative human viewpoint without revelation. Furthermore, the archangel suggests the possibility of other relative viewpoints, albeit by telling Adam not to think of them: 'Dream not of other worlds, what creatures there | Live, in what state, condition, or degree' (VIII. 175–76).

As well as a more modern notion of space that is homogeneous and continuous, the poem is very aware of a more traditional, Aristotelian idea of place, and uses this theme to work through a number of moral issues — particularly that of our place in creation and our relation to God — in a way which has some affinity with Aristotelian ideas about the impulse of objects towards their final, rightful place. Place in Milton is not just location; creatures are deliberately placed in particular locations by God, the subject of the whole work being, 'the loss thereupon of Paradise *wherein he was* *placed*' (Book I. *argument*, my emphasis). Punishment and justice are effected by expulsion and imprisonment — acts of removal, re-placing, and restriction of movement — and tied to specific locations and their distance from God. Similarly, order (including creation itself) is established by acts of containment and the maintenance of boundaries, while the disruptive forces of the poem transgress these bounds. Satan on his first entry into Paradise, 'At one slight bound high overleaped all bound | Of hill or highest wall' (IV. 181–82), the repeated word *bound* emphasizing the transgression by weakening its very sense. We find moral trajectories in the descriptive language of the poem and are invited to contrast, for example, the upright forms of paradisal Adam and Eve, 'Godlike erect' (IV. 288), to the downward bent of Satan, 'Oh foul descent!' (IX. 163). This is also explicitly linked to place of habitation. The narrator links 'purity and place and innocence' (IV. 745) in discussing Adam and Eve's connubial love, while a hundred lines later, Zephon reveals the contrast in Satan's bearing since his fall and expulsion:

> Think not, revolted spirit, thy shape the same [...]
> As when thou stoodst in heaven upright and pure;
> [...] thou resemblest now
> Thy sin and place of doom obscure and foul. (IV. 835–40)

Syntactically, 'upright and pure' can apply to both Satan's former self and to heaven, while Satan now resembles both his sin and his current place of doom, suggesting equivalence between the state of sin and the place of hell.

Despite the congruity of these metaphorical readings of place that suggest a correlation between location and rightness, directionality and morality, place in *Paradise Lost* is incompatible with the idea that bodies come to rest once they are in their correct and final place. There is a recurring theme of rest in the poem with numerous examples of the restfulness of paradise, 'as nature wills, night bids us rest' (IV. 633), contrasting with the agitation of hell, 'where peace | And rest can never dwell' (I. 65–66). However, unlike the Aristotelian system where rest is a function of physical place and predetermined according to elemental composition, rest in *Paradise Lost*, even when externalized by the poem's characters, is really a function of mental state and does not have a fixed location. Even in paradise, Eve (after her Satanic dream) experiences 'unquiet rest' (V. 11), and Satan and his crew are 'dislodged, and void of rest' (VI. 415) before they are cast out of heaven. When Adam and Eve are expelled from paradise, they are not moving towards or further from their fixed place of rest, but have the option, ‘where to choose | Their place of rest,’ (XII. 646–47). It seems that in Milton one’s sense of place is a psychological rather than physical impulse. Although presented as vain posturing, there is a ring of truth to Satan’s words, ‘The mind is its own place, and in itself | Can make a heaven of hell, a hell of heaven.’ (I. 254–55) Sadly for Satan this truth spells his self-condemnation, ‘which way I fly is hell; myself am hell’ (IV. 75), as he refuses to allow himself a ‘place | Left for repentance’ (IV. 79–80).

In *Paradise Lost*, Milton adds to the account in Genesis the destruction of Eden (XII. 636), its foretold move ‘Out of his place’ (XI. 831) by the flood, and the reason given for these acts. Michael tells Adam that the flood comes:

> To teach thee that God áttributes to place
> No sanctity, if none be thither brought
> By men who there frequent, or therein dwell. (XI. 836–38)

In the Bible the reason given for the flood is the ending of fleshly corruption and violence (Genesis 6. 11–13). Milton introduces an idea of the sanctity of place, but one that is conditional on man’s beliefs and actions, not on special properties of place. Michael Lieb argues that the fall and expulsion from paradise necessitates a readjustment of what holy place means: that external place becomes deprived of sanctity and that holy place becomes interiorized as the ‘paradise within’.[42] I agree with the view of place that Lieb ends up with, but not that it is a result of the fall or expulsion, but rather that an internalized sense of place is a consequence of being free to fall. It is the discontent of angel and man, expressed in terms of place, which leads them to fall, not their falls that lead to their discontent and thus displacement. As mentioned, both Satan and Eve experience restlessness before their falls. Satan ‘dislodge[s]’ (V. 669) his camp before the fall of the angels (as we know from the possibility of Abdiel’s return at the end of Book V), and Eve, feeling the restraint of dwelling ‘In narrow circuit’ (IX. 323), leaves Adam’s presence, occasioning her temptation.

Brady argues that the space of *Paradise Lost* is not ‘the absolute, naturalized space of the physical world’. She reads it in the context of Aristotelian place and concludes:

[42] Michael Lieb, ‘“Holy Place”: A Reading of *Paradise Lost*’, *Studies in English Literature, 1500–1900*, 17 (1977), 129–47 (p. 145).

> we situate *Paradise Lost* on the keen edge of modernity, at a moment before space has yet become absolute, an aspect of either the physical world or perception itself. Poised on this threshold, the poem registers emergent features of modern space, but also their disruption by the persistence of place. We are thereby reminded that space was not always part of experience, but something that had to be imagined before it could be inhabited.[43]

Brady's reading of the space and place of *Paradise Lost* is for the most part very perceptive, but she presumes an ontological reality for absolute space and also does not register where Milton's ideas of place diverge from Aristotle. By considering absolute space as an epistemological construct — indeed as something that has to be imagined — and something that can only be understood in terms of relative experience, it becomes possible to accommodate what Brady calls the persistence of place by means of relativity and the centrality of the thinking and perceiving subject. The psychological interpretation of place that I offer, unlike an Aristotelian interpretation, does not contradict the more modern (albeit non-specific) physical presentation of space we have seen in *Paradise Lost*. It is also more compatible with Newtonian ideas; Newton's physical definition of place is simply the space that a body occupies.[44] By internalizing any special properties of place as part of the psychological experience and construction of spatial relations by the thinking and feeling individual, Milton avoids physical contradiction at a systemic level whilst observing an emotional relativity that in some ways corresponds to the creaturely, relative experience of space and the psychological experience of thinking about space. So doing, he liberates morality from physics in a similar way to Newton's liberation of physics from morality in his rational universe with its homogeneous space, force-driven motion, and purely numerical concept of place. As such, Milton uses Aristotelian concepts of rightness of place in a metaphorical way, but can also give rational meaning to free choice.

As we have seen in Newton's writings, in Milton there is some degree of identification or affinity between God and space. Both writers imply the possibility of material

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[43] Maura Brady, 'Space and the Persistence of Place in *Paradise Lost*', *Milton Quarterly*, 41 (2007), 167–82 (p. 178).

[44] *Principia*, p. 409.

identity but then pull back from this to varying degrees, Newton ending up with a purely conceptual and metaphorical identity, Milton with a more complex, mixed identity. In both writers, the relationship between God and space is explored in a way that is intimately connected with the action of human thought at the boundaries of the unknown.

In Milton's work there is a material connection between God and space through the idea of creation *ex Deo.* The author of *De Doctrina Christiana* disproves, on logical and philological grounds, the orthodox concept of creation by God *ex nihilo* and surmises that as the world was created out of something, but that there could not be a pre-existing substance independent of God; the raw matter of creation must have come from God himself, divided from him by the retraction of his will.[45] This act is demonstrated in *Paradise Lost* by God's words to the Son at the creation, as recounted by Raphael:

> ride forth, and bid the deep
> Within appointed bounds be heaven and earth,
> Boundless the deep, because I am who fill
> Infinitude, nor vacuous the space.
> Though I uncircumscribed myself retire,
> And put not forth my goodness, which is free
> To act or not, necessity and chance
> Approach not me, and what I will is fate. (VII. 166–73)

The resulting substance of God's uncircumscription and retraction is widely held to be the 'dark materials' (II. 917) found in the 'vast abyss' (I. 21) or 'womb of nature' (II. 911) that is the realm of chaos or the boundless 'deep'. Because these materials are so strongly identified with the location that is chaos, and again with the locations they become — the deep itself is bid to *be* heaven and earth — there is a sense of identification between this material and with space. However, in withholding his goodness from matter and making it 'Sufficient to have stood, though free to fall' (III. 99), God creates an affinity, but significant lack of identification, between himself and matter, turning that former identification into memorial or conceptual rather than

[45] George Newton Conklin, *Biblical Criticism and Heresy in Milton* (New York: King's Crown Press, 1949), pp. 67–74; see also *CPW*, VI, 301–08.

material identification. As with the relationship between Adam and Eve, the important relationship is semiotic, and not concerned with material identity.

There is also a potential identification between God and space as a framework. God says, 'I am who fill | Infinitude, nor vacuous the space'; the idea that God fills infinitude and ensures that space is not empty suggesting that space and infinitude are separate from God. However, the principle occasioning Milton's theory of creation *ex Deo* — that there can be nothing that pre-exists God — suggests that any notion of space or infinity that is separate from God is not real in the same sense. By making *I am* intransitive and drawing attention to it by not resolving the difficult syntax, Milton also potentially removes the idea of thingness from God, perhaps echoing Newton's distinction between God who is infinite and infinity itself, or Henry More's concept of spiritual extension.

Elsewhere in *Paradise Lost* something akin to absolute space or a wider frame of reference than the relative experience of creatures is hinted at by the inclusion of vast angelic perspectives and even ultimately God's limitless perspective (albeit in accommodated form). When Adam talks of the 'Unknown, which human knowledge could not *reach*' (my emphasis), he uses a common spatial metaphor to compare his epistemological capacity to that of 'higher' beings. However — like Newton's line, imagined as being beyond distance, or Boyle's notion of things that are beyond proportion — the narrator locates God, 'High throned *above all height*' (III. 58, my emphasis). The contradiction of height above height takes God outside of the human spatial framework and emphasizes the accommodated nature of the semantic field of height that persists throughout the passage. From this seat, God beholds a uniquely inclusive panorama, 'His own works and their works at once to view' (III. 59), and looks, 'from his prospect high, | Wherein past, present, future, he beholds' (III. 77–78). God's vision encompasses concurrently successive temporalities, and hints at an altogether wider visual frame by his ability to see the whole of creation, the whole four-dimensional manifold in one view. This exploration of the expansive scope of God helps the reader to experience the thinking of space beyond relative space by mentally tracing the inhuman line of sight.

Sarkar describes Milton's 'special kind of word play which helps to create a tremendous sense of space' in *Paradise Lost*. She comments on the sense of expansion in the synechdochic image of the world hanging by a golden chain, 'in bigness as a star | Of smallest magnitude close by the moon' (II, 1052–53): 'although visually reductive for the moment, the image keeps alive simultaneously the possibility of immense enlargement.'[46] This possibility occurs, Sarkar suggests, by means of the clash between 'bigness', 'smallest', and 'magnitude', 'the self-infolding of world into star, and the simultaneous expansion of star into world' (ibid.). Like the confusion of scales found in Hooke's work, which encouraged a sense of encounter or of the reader entering into the micro world, these intense optical effects create an intimate experience of space in the reader's mind. They emphasize the relativity of perception (in this case of scale), and keep the image in the mind's eye moving, the reader not just seeing, but actively tracing a path. In being both reductive and yet also keeping alive the possibility of enlargement, the effect is one of continual expansion. This telescoping is dynamic in the Newtonian sense, and the reader is both witness to and participant in the phenomenon.

Another view of an unknown and potentially unknowable (indeed 'secret') space, which uses a similarly expansive technique, occurs when — with Satan, Sin, and Death — we first look upon chaos:

> Before their eyes in sudden view appear
> The secrets of the hoary deep, a dark
> Illimitable ocean without bound,
> Without dimension, where length, breadth, and height,
> And time and place are lost[.] (II. 890–94)

The idea of perspective is emphasized in the first line as the reader starts at the eye of the viewers and traces the lines of sight out to their view. A semblance of that view is created in the reader's mind by the use of familiar images (*ocean* and *bound*), and words of measurement (*dimension*, *length*, *breadth*, *height*, *time*, *place*), but is destabilized by the negating words (*illimitable*, *without*), culminating in the ripping away of any surety of the containable framing of the scene with the delayed word *lost*, which enacts the stripping away of measurement. Catherine Gimelli Martin reads a theology of relative space in Milton in the context of Pascal and his appreciation of the significance of the 'decentered spaces' of man and God once the new science opens up to infinity and the void. She describes the concept of *zero* which is transformed in this period from a 'merely negative to a positive absence', and argues that for Milton and Pascal, 'God can be approached only by inventing a new and ironic allegory of absent

[46] Sarkar, p. 2.

presence based on the analogy of the new absences discovered in his spatial universe.'[47] I believe that Martin's reading can be fruitfully combined with an appreciation of Milton's application of the methods of apophatic theology to his description of chaos, to create that sense of positive absence, which is similar to his description of God or of the duality of sight and the absence of sight. We feel this 'decentering' of space in the literary and cognitive effects of Milton's description of chaos. He makes the reader think spatially on a grand scale and then push beyond a static, bound image so the experience is one of continual expansion, which decenters the exterior space being explored by making it understandable in terms of movement or trajectory rather than fixed location. This expansive tracing also draws attention to and decenters the interior mental space of the thinking subject tracing those trajectories. With the stripping away of measurement the security of relativity in its sense of relatability is destabilized, leaving only relativity in the sense of a subjective experience of space. However, rather than undermining knowledge, as with the descriptions of God, this expansiveness captures a sense of reaching beyond the limits of the human in its very uncertainty.

This expansiveness contrasts with the knowable — indeed experimental — spaces of Eden and earth, which are decidedly measureable, and, like Boyle's experimental spaces, are made concrete by detailed description. When Raphael describes the heavens as a book of God set before Adam, it is specifically with the intention of helping him to measure time: 'Wherein to read his wondrous works, and learn | His seasons, hours, or days, or months, or years' (VIII. 78–79).

As well as Adam, Milton includes in his epic specifically scientific observers by means of his allusions to Galileo. Milton's knowledge of Galileo's *Dialogue Concerning the Two Chief World Systems* has been demonstrated, although the meaning of these allusions (and whether they are for or against the new science) is contested.[48] McAdam notes that Satan's invention of the cannon and gunpowder recalls the discussion of the cannonball from the *Dialogue*, pairing a Galilean paraphrase from the *Dialogue*, 'All truths are easy to understand, once they are discovered; the point is, to discover them', with the admiration of the rebel angels for the Satanic act:

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[47] Catherine Gimelli Martin, '"Boundless the Deep": Milton, Pascal, and the Theology of Relative Space', *ELH*, 63 (1996), 45–78 (p. 56, 72).

[48] See Ian McAdam, 'Milton, Satan, Galileo, and Gunpowder', *Notes and Queries*, 253 (2008), 289–91, for a brief survey and critical history.

> The invention all admired, and each, how he
> To be the inventor missed, so easy it seemed
> Once found, which yet unfound most would have thought
> Impossible[.] (VI. 498–501)[49]

McAdam, lured by the association of Galileo and Satan, hypothesizes that Milton could be casting doubt on the validity of scientific endeavour, offering support for the pro-Satanic faction, or was an 'ideologically or psychologically conflicted author.'[50] However, what McAdam misses is the difference between the two passages: Galileo is talking about discovery, Milton's rebel angels, invention. The difference is between the roles of observer and progenitor, something Satan wilfully confuses throughout the poem. Satan's experience of relativity is taken to the extremes of interiority with his solipsistic denial of God's agency, such as in his autochthonous parody of empirical thinking, cited above. He also displaces God's agency in creative acts when he says 'Space may produce new worlds' (I. 650). The irony of this is that Satan's relative denial of God simultaneously affirms the truth of God's creative power by reference to the wider frame, of which Satan has no understanding. Space is not just the space that Satan experiences, but is also the 'dark materials' (II. 916) of creation *ex Deo*; God's method of creation by the appointment of boundaries and divisions (VII. 165–67); and even God himself, the 'I am who fill | Infinitude' (VII. 168–69). By failing to acknowledge the absolute (whether epistemological or ontological) that the relative implies, Satan fails as a fit reader and is unable to truly value anything, including his own words.

It is the exploratory role of the discoverer (the role we saw in Newton's description of himself as a boy collecting pebbles on the shore which aligns with Milton's idea of a fit reader and seeker of truth) that we find foregrounded in the other allusions to Galileo.[51] This observational, searching role fulfils the epistemological potential for man and Milton's educational mission expressed in *Of Education*. The allusions to Galileo emphasize the limited vantage point of the human observer with reminders in each allusion of our restricted capacity, for example the description of the horns of Venus, 'though from human sight | So far remote, with diminution seen' (VII.

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[49] McAdam, p. 290.

[50] McAdam, p. 291.

[51] I. 287–91, III. 588–90, V. 261–63, VII. 366–69, VII. 577–581.

368–69). However they also demonstrate the glimpse of something greater that even this limited vantage point can offer, when we are taught to see rightly. The way to God's house is described by Raphael to Adam:

> A broad and ample road, whose dust is gold
> And pavement stars, *as stars to thee appear*,
> Seen in the galaxy, that Milky Way
> Which nightly as a circling zone *thou seest*
> Powdered with stars. (VII. 577–81, my emphasis.)

The allusion acts as a poetic telescope, allowing the narrator to mediate between his cosmic vision and his human reader, drawing analogies to known or imaginable acts of human vision and showing us where and how to look. This is discovery, not invention, and the visible road of stars we are taught to see, leads to the invisible.

And so we return to the question of how to bridge the gap between the invisible and visible, the relative and absolute, the human and divine. So far we have seen examples of inference from the visible and faith in possibility. Both rely on an act of imagination to conceptualize something beyond the self and beyond one's own experience. As with Newton's conception, it is the relationship between absolute and relative that enables us to understand each of them. As such is not just the content of the conceptualization that is important, but the imaginative act itself, which enables the relationship between absolute and relative and connects man to God in its expansive creativity. In *De Gravitatione*, Newton likens the creative will of God to the will of man to move his own body. He asserts that, 'the analogy between the divine faculties and our own may be shown to be greater than has formerly been perceived' (*PW*, p. 30). In *Paradise Lost* Raphael reveals that human discursive reason is related to angelic intuitive reason, 'Differing but in degree, of kind the same' (V. 490), and in *Of Education* suggests imitating God as a method of regaining knowledge of him (*CPW*, II, 367). Laïla Ghermani suggests that Milton's Arminianism allows that, 'visible realities are indeed able to reflect divine realities in truth because the difference between them is not ontological but corresponds only to a difference in scale between "great things" and "small"'.[52]

Space seems to play a particularly important role in this dynamic. When Newton describes space as an 'emanative effect' of God in *De Gravitatione*, he creates a necessary link between space and existence, but in doing so also creates a parallel between the act of God creating space and the creative acts of the creaturely imagining of space. Likewise, Milton urges his readers to re-enact a spatial creation in the mind. His repeated emphasis on the act of witnessing gives a sense that the poem's worlds and locales come into being with that act, that looking is performative ('Before their eyes in sudden view appear' (II. 890)). Like Boyle, Milton makes his readers witnesses to the events of the poem and similarly schools them in ways of looking and thinking so that they can become participants in its mental activities and experiments. A frequent trope is the defining of space by filling it with sound or light, our tracing of boundaries following lines of sight or guided by echo, and our experience of relative space mimicking God's creative act of thinking and ordering space into being.[53] Milton emphasizes the limitedness of relativity and warns the reader of the solipsism of Satan, but also shows us the wonders of creative acts of outward looking imagination, which allow us glimpses of things invisible to mortal sight. Our experience of thinking about space brings us closer to the creative act of God.

Conclusion

Despite popular mistrust — particularly in religious contexts — of the body and the passions, Milton incorporates them into his Edenic epistemology. He shows what is usually considered a perfect state of knowledge to be a state not fixed, but — like the natural philosophical project of his contemporaries in the Royal Society — a process of learning, ennobling the state of not-knowing and the various tools and methods used (sensory, discursive, rational, and linguistic) to achieve knowledge through experience

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[52] Laïla Ghermani, '"That I may see and tell | Of things invisible to mortal sight": Representing the Invisible in *Paradise Lost*', in *Milton, Rights and Liberties*, ed. by Christophe Tournu and Neil Forsyth (Bern: Peter Lang, 2007), pp. 255–62 (p. 258).

[53] See for example the lines: 'At once as far as angels' ken he views' (I. 59); and 'all the hollow deep | Of hell resounded' (I. 314–15).

and trial. Milton also ennobles the state of fallen man, presuming for him the dignity of sufficiency to judge rightly of knowledge, and the ability to regain the knowledge of unfallen man, even in his fallen state. The tools by which man can approach this knowledge integrate the rational and bodily; they are passionate (rightly tempered in virtue and love), sensory and intellectual (in contemplation of the visible world), and faithful of the grace that will complete his elevation. Man's example in achieving this end of learning is the Son, whose humanity, bodily experience, and faith are shown to be his strength. Milton also provides a second example in the self-conscious presentation of his own subjective experience and flawed agency as a writer, using emotion and blindness to create value and teach insight. Milton does not deny the deceptive potential of sensory perception, but his exploration allows that its inherent unreliability can in itself lead to true inner vision. He holds this insight (whether vatic or rational) in duality with sensory experience, allowing the two to inform one another, whether it be spiritual and sensory vision, sight and the absence of sight, or the synechdochic duality of immanent accommodation, which holds the scriptural vision of God to be both actual and representative of something more. Milton aligns reason with the image of God, which we should aspire to imitate in order to reach that end of learning (*CPW*, II, 492). This implies that reason is accommodated to our fallen state, and therefore that there is real truth in its accommodated form. Milton also describes reason as choice, which encapsulates the necessity of nescience. Like Newton's portrayal of the relationship between the absolute and the relative, Milton understands the interconnectedness of these two modes; it is only by means of the visible that we can know of the invisible, but then in turn the invisible recontextualizes and allows us to understand more fully the visible.

These epistemological themes are also echoed in the spatiality of *Paradise Lost*. The poem's bounded space — the garden of Eden — acts as an observational space as the reader studies Adam and Eve and their natural habitat; an experimental space as we watch their obedience test; and a point of relative reference in conceptual space as we follow the wider cosmic portrayals in the narrative and the cosmic speculations of the characters. The space of the poem is first and foremost mediated through human relativity and conceived in relation to the limits of human knowledge. However, its exploration at the limits of these boundaries which the poem's vast cosmic scope — with its imagining of heaven, chaos, hell, and the space in between — affords, encourages the reader to use his or her experience of thinking about space in new and expansive ways to approach the invisible by means of the visible, and the unknown by means of the known. The limited, solipsistic thought of Satan, who uses false, pseudo-scientific logic to deny God and who keeps himself emplaced in hell as a psychological function of his denial, serves as a negative example to the reader. We are instead encouraged, by the portrayal of the inquisitive Adam and his lessons from Raphael, to look to creation as a sign of the creator, and to do so with humility and wonder.

Epilogue

In his seventh prolusion, 'In Defence of Learning' (written in the late 1620s and first published in 1674), in which he advocates the knowledge of natural science and expresses favour towards Baconian and experimental methods, Milton declaims:

> So at length, my hearers, when universal learning has once completed its cycle, the spirit of man, no longer confined within this dark prison-house, will reach out far and wide, till it fills the whole world and the space far beyond with the expansion of its divine greatness. (*CPW*, I, 296)

This statement connects an internal sense of selfhood — the confined spirit of man — with a reaching out into the external space of the world (and beyond) through universal learning, which expands that which is divinely great in the spirit of man. Like Newton's image of himself as a boy playing on the shore, the great ocean of truth undiscovered before him, there is a vast expansiveness — even transcendence — to this image of learning that contrasts with the cloistered shallowness of self that is characteristic of the book learner from *Paradise Regained*, whose collection of 'pebbles' prompted Newton's analogy. This confident image from the young Milton captures the vast spatial capacity of the imagination to trace an infinite exterior within the mind, and connects this capacity to divinity in a manner reminiscent of Newton's metaphor of space as God's sensory.

In my thesis I have traced the epistemologies of Hooke, Boyle, Newton, and Milton, all of whom explore the tensions between a belief in methodologies rooted in observation, experience, and experiment, and the insecurities attendant on a reliance on subjective perception. The four thinkers each accommodate the concept of doubt into their structures of knowledge by various means, particularly by the assumption of the consistency of the laws of nature and the admission of hypothetical or uncertain knowledge on a contingent basis, each incorporating these ideas into their work with varying degrees of confidence in the capacity of mankind to know and reach beyond his limits. I have shown how these writers engaged with uncertainties and emergent spatialities in microscopy, the study of air, mathematical physics, and literature. I have traced relationships between space as object, the space of the imagination, and the space of the page, arguing that spatiality is a key component in knowledge-making, allowing for new types of seeing and the recognition of relationships. Spatiality foregrounds the relativity — this reliance on the relation between objects understood in relation to the self — that is at the heart of scientific uncertainty but which is inherent to human knowledge. As well as contributing to the process of making new knowledge, the spatial strategies of these authors also have an epistemological function in accommodating and working with uncertainties.

In Chapter 1 I showed how Hooke uses visual, spatial modes — including tables, lists, themed groups, illustrations — to gather and order his data, across time and space and at one view, in order to see patterns and relations so as to be able to raise axioms from it. His illustrations, as well as serving as inscriptions of data which can themselves be grouped, also represent the outcomes of this practice by depicting an understanding of a microscopic object developed by aggregating the knowledge gleaned from the patterns and relations understood from various observations of various specimens. I argued that Hooke's methods of seeing are interpretive and that he is not merely an amanuensis for the microscope as has previously been suggested. The principle of relation also holds at a more abstract level as I have shown in the methods of analogy Hooke used to explore the micro world, both in terms of the known macro world and on its own terms, embracing the encounter with the unknown and beginning the plotting of new knowledge maps, rather than using a purely assimilative approach. Spatial arrangement is a key feature of his theory of mind and memory, and echoes his incremental approach to knowledge.

In Chapter 2 I demonstrated a tension between Boyle's strong adherence to an epistemology of nescience and his desire to seek out natural philosophical truths, a tension which is echoed in a descriptive style that contains a mix of highly detailed narrative but also summary deferrals to the practitioner's experience; in illustrations that don't attempt to portray the hypothesized object air but which do depict experimental apparatus with a high level of detail; and also in his archive, which shows some desire to order material so as to reveal new knowledge in a manner akin to Hooke, but which also resists premature systematization. In his investigations into air, as well as his concern with the demarcation of the experimental space that allows him to 'see' and work with the invisible air, Boyle also works on recreating the experimental scene for the reader. I offered a new reading of this feature to supplement Shapin and Schaffer's popular interpretation of it as a technique to create virtual witnesses who can assent to his hypotheses, suggesting that it can also be seen as a technique for inscribing a mental space for the reader, a mental laboratory in which he or she can perform the sort of imaginative thinking required for a natural philosophy of a substance like air, which is reliant on hypothesis and inferential methods.

In Chapter 3, I argued for an intimate connection between Newton's epistemological practices and his conception of space. His dynamics (which itself relies on his epistemological principles of assuming consistency and admitting contingent knowledge on methodological grounds) requires a backdrop of absolute space in order for the relative space and motion that we perceive to be understood. I concluded with Stein and DiSalle that absolute space exists as a necessary epistemological construct for Newtonian dynamics. Furthermore, I showed that Newton's absolute and relative space are not separate but are intimately connected as we can only understand them in terms of each other. This relation is echoed in Newton's spatial exploration of the nature of God, who must be similarly understood by man in terms of an abstract corrective to relative understanding.

In Chapter 4 I demonstrated some of the concerns and approaches to method in Milton's epistemology that are similar to those of the Royal Society practitioners studied here. Milton's emphasis on learning and faith ennobles the limits and gaps to man's knowledge at the same time as aspiring beyond those limits. I showed how Milton uses the metaphoric qualities inherent in language — the spaces between signifier and signified — to interrogate and understand relations, and also how he calls forth to the imagination a range of spaces and bounds by means of which he works through questions — both physical and psychological — of man's relation to and place in the world. I argued that Milton's spatiality is relative, but also expansive, tracing lines of sight to their furthest extremes and gesturing towards an understanding that transcends spatiality as we understand it, that is, towards God. Like Hooke's understanding of the micro world by analogy with the macro, Boyle's illative knowledge of air, and Newton's imbrication of relative and absolute, Milton approaches knowledge of the invisible by means of the visible, and in turn allows the invisible to recontextualize and give greater meaning to the visible.

In each of these case studies I have explored the relationship between external and internal space in the thinking and perceiving subject, placing it in the context of epistemology and building on Steven Connor's assertion — at least with regards to the thing that is space — that 'thinking about things is unavoidably a kind of thinking about the kind of thing that thinking is'.[1] Further to this unidirectional relation between thinking and things, my case studies, which examine this in relation to space, have also revealed a more complex dialogue between interior (thought) and exterior (thing). This occurs in the ways that processes of thought and perception are externalized on the page and with instruments of viewing; the way that objects are brought into the mind; and the way the mind creates infinities within by tracing expansive external spatialities.

It is my hope that my work supplies a gap in the knowledge of processes of understanding and knowledge-making in this foundational period for the modern thinking of space, and that the findings of my case studies also contribute to the understanding of perception and epistemology, particularly with regards to their relativity and the dialogue of interior and exterior, in these four writers. I trust that my methods of analysing content by means of a close attention to the visual, verbal, and mental tools of thought and the connections between them has brought out rich new readings of these four authors and emphasized new significances in modes of transmission that can be applied more widely.

The conclusions of my thesis suggest several further lines of enquiry for future research. One productive project would be to apply the methods of this thematic study more widely to other authors of the period, including outside of England, both in the sciences (for example Descartes, Leibniz, and Christiaan Huygens) and in imaginative and esoteric literature (writers such as Marvell, Cavendish, Traherne, and Henry More). The approach could also be applied to preceding or subsequent periods.

Another project suggests itself in the emergent dialogue between internal and external space in the relation of thing to thinking thing. By tightening the thematic focus from a broadly inclusive idea of space to the specific notion of infinity — a transcendent idea that gestures beyond our possible comprehension of it — I believe the researcher will also move from a more general understanding of knowledge-making to the dynamics of the specific moment of encounter with the unknown and the act of reaching beyond a limit. By examining how early modern thinkers conceive of an idea of perfection or of limitlessness as an object, I propose we can come to understand the interior expansiveness of the thinking subject's mind.

The third strand of future research growing out of the work on metaphor and semiotics in my doctoral project is an investigation into the spatiality of early modern

[1] Connor, 'Thinking Things', (2010), p. 3.

language, in particular the spatiality of linguistic structure and organizational place in early modern artificial language projects, such as Francis Lodwick's *A Common Writing* (1647), which classifies reality and encodes it in terms of location within a scheme. This would be particularly fruitful if paired with a cognitive reading of early modern metaphor in the context of the mental space theory of Fauconnier and Turner, which, developed in the 1990s is only recently starting to be applied to early modern literature and science. I suggest that a related study of metaphor and language schemes will draw out the nuances of the cognitive spatiality of language and its role in man's search for an understanding of himself in relation to the world.

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